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THE POTENTIAL IMPACT OF GLOBAL WARMING ON AGRICULTURE

HEARING

BEFORE THE

COMMITTEE ON AGRICULTURE, NUTRITION, AND FORESTRY UNITED STATES SENATE

ONE HUNDREDTH CONGRESS

SECOND SESSION

ON

THE POTENTIAL EFFECTS OF GLOBAL WARMING AND GLOBAL CLIMATE CHANGE ON U.S. AGRICULTURE AND FORESTRY

DECEMBER 1, 1988

Printed for the use of the
Committee on Agriculture, Nutrition, and Forestry

U.S. GOVERNMENT PRINTING OFFICE

92-806 WASHINGTON : 1989

For sale by the Superintendent of Documents, Congressional Sales Office
U.S. Government Printing Office, Washington, DC 20402

S161-19

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THE POTENTIAL IMPACT OF GLOBAL WARMING ON AGRICULTURE

THURSDAY, DECEMBER 1, 1988

U.S. SENATE,
COMMITTEE ON AGRICULTURE, NUTRITION, AND FORESTRY,
Washington, DC.

The committee met, pursuant to notice, at 9:35 a.m., in room SR-332, Russell Senate Office Building, Hon. Patrick J. Leahy (chairman of the committee) presiding.

Present or submitting a statement: Senators Leahy, Boschwitz, and Bond.

STATEMENT OF HON. PATRICK J. LEAHY, A U.S. SENATOR FROM VERMONT

The CHAIRMAN. Good morning.

I have often thought that during the recess time it would be less hectic around here. But with all the leadership races and the Steering Committee, which is meeting and will take me out of here during part of this hearing, the arcane aspects of the Senate that we do not see in the big hearing rooms are really taking place. In electing our Majority Leader this week, some of us jokingly thought that there should have been maybe a puff of white smoke coming out of the chimney to announce the selection. [Laughter.]

It was as close as we will ever get to the election of a Pope over here. But now we go to what really counts. Most people think that the legislation that will be on the floor to deal with the budget, to deal with issues like that, are the real matters affecting the Senate. Not so. The real issues are taking place in a committee called the Steering Committee where we decide who gets which committee assignments.

I am a member of the Steering Committee, and I am going, at some point, to have to leave for part of that meeting, for a critical vote relating to the Agriculture Committee. We will have other Senators here to take over. But that is why it gets a little bit disjointed.

I did want to have this hearing before we started the next Congress. Because as we get into it, I was afraid that some of the issues we are going to discuss here might get submerged, even though they are going to have a major impact on what we do in the next Congress.

In the next 4 years, for example, we are going to make major decisions about how this Nation will address the threat of global atmospheric pollution.

This morning we are going to examine, in some depth, the issues surrounding the potential effects of global warming and global climate change on U.S. agriculture and forestry.

More than any other sectors of our economy, agriculture and forestry are very sensitive to climate.

You and I listen to the weather report to decide whether we will wear a coat tomorrow. The farmer listens to the weather report to decide whether or not he will have a crop this year, or even next year.

As we learned this year, even in a stable climate like ours, the expected droughts, storms, and floods make agriculture a very risky business. How much more sensitive would agriculture and forestry be if the climate itself is changing?

So this is really the time to start looking at these issues.

First, I am pleased to note, we have a new President who has pledged new initiatives in this area, and I will work with President-elect Bush in that area.

Second, we have also just come through the worst drought in my lifetime.

Is the drought a forerunner of things to come? This is a question we have to ask.

Four of the hottest years recorded in the past 100 years have occurred in this decade, in the 1980's.

Third, the EPA has issued a draft of their report to Congress, "The Potential Effects of Global Climate Change on the United States."

Several years ago, as evidence mounted that global warming was occurring, I was serving as the senior majority member of the Appropriations Subcommittee that was responsible for the budget of the Environmental Protection Agency.

Because of my concern about the potential impacts of global warming, at my request $5.6 million were added to the budget of the EPA to assess the potential effects of global climate change on the United States.

Now we learn from that EPA report just how very, very sensitive our agriculture and our forests would be to global warming. The report shows what could happen if we sit here and do nothing about it.

If we do nothing, many soybean farmers in the Southeast could be out of business. If we do nothing, warming could drive the sugar maple right out of Vermont, which would be a catastrophe for my State. Many other changes will take place if we do nothing, all of them adverse to this country.

Two of the principal witnesses will testify on the findings of that study today.

The central question before the Congress is: What can or what should we do? After all we are talking about uncertain effects that may take place at some time in this or the next century.

Congress cannot seem to make up its mind about whether it wants a 2-year budget, or 1-year budget, let alone focus on the effects of global warming which may not occur for several decades. We are talking about what we are going to do about the climate in the next century.

But there is too much at stake to let our normal cynicism, or some might say realism, about congressional leadership hold sway.

It is our job to worry about the long term future of American agriculture and forestry.

There appears to be an emerging consensus in the scientific community that we face a warmer world. A 1987 National Academy of Sciences report indicated that a 1.5 to 4.5 degree Centigrade increase in global temperatures is likely if carbon dioxide doubles. Carbon dioxide is likely to double during the next century.

I hope we will find answers to three questions this morning:

First, what is the consensus of scientific opinion on global warming?

What effect will it have on American agriculture and forestry?

What should the Federal Government's response be to this situation?

We have brought together an excellent group of witnesses to address these questions.

The first panel will be Dr. John Firor, who is the Director of Advanced Studies at the National Center for Atmospheric Research; Dr. Cynthia Rosenzweig of Columbia University, Department of Geography, if Dr. Rosenzweig could join us up here; and Dr. William Moomaw, the Director of the Climate, Energy and Pollution Program with the World Resources Institute.

We are delighted to have so talented a panel here. It is an honor for us to have you here, and before the first panel begins we will start with Senator Bond, former Governor of the State of Missouri, a good friend of mine who has joined us here.

Did you have an opening statement you wanted to make before we go to the panel?

STATEMENT OF HON. CHRISTOPHER S. "KIT" BOND, A U.S. SENATOR FROM MISSOURI

Senator BOND. Thank you, Mr. Chairman. I will make a few comments and submit this prepared statement for the record.

I certainly commend you for choosing to hold a hearing on this important subject. Yesterday I met with representatives from the Food and Agricultural Policy Research Institute at the University of Missouri at Columbia. And one of the subjects which they discussed with us was the concern over warming at that time, and I knew that this hearing was going to be going on today. So we are very much interested in finding out about the consequences of abnormal weather patterns. The drought this past year obviously had a great impact on Missouri agriculture as well as the rest of the country.

We realize that we may or may not have a trend established yet, but if there is such a trend, obviously we are going to have to take many steps to address it.

I was particularly distressed to learn that methanol may cause problems, and there are other sources of energy which should be considered. So I join with you in looking forward to hearing what our distinguished panelists have to say today.

[The prepared statement of Senator Bond follows:]

STATEMENT BY SENATOR CHRISTOPHER S. BOND (R-MO.)
BEFORE THE SENATE COMMITTEE ON AGRICULTURE, NUTRITION AND FORESTRY
THURSDAY, DECEMBER 1, 1988, 9:30 A.M.

Mr. Chairman, it is a pleasure to be back in this setting and I commend you for choosing such an important issue--how global warming will effect our agricultural sector. While many scientists and researchers disagree as to the extent of global warming, we as legislators cannot discount the long-term consequences associated with an imbalance in the Earth's regulatory system. Perhaps nowhere will climatic changes be more serious than in agriculture.

As my colleagues on this Committee will attest, we are well schooled in the consequences of abnormal weather patterns. This summer's drought had an enormous impact on our nations farmers and ranchers--and we're not out of the woods yet. Although we didn't see large increases in food prices at the consumer level it was only because of sufficient stocks to sustain demand.

Mr. Chairman, can you imagine the effects of a sustained drought--one that lasts for years on end? What about temperature changes leading to shifting crop patterns? In fact, it becomes even more troublesome when you consider that the effects will be world-wide in scope.

Reading through the CRS report requested by my friend from Vermont, I was very interested in the point made regarding

methanol. In recent years, we have be searching for viable alternative motor fuels. While methanol, derived from coal or biomass, may indeed become an important alternative fuel we must ensure that there is a net gain to the environment. The CRS report indicates that methanol produced from coal may double net carbon dioxide production per mile driven. I feel these new technologies must be thoroughly researched to ensure that we are not trading one environmental concern for another.

I look forward to learning more about this issue and would hope all of our colleagues participate in efforts to reduce the threat of global warming. In fact, I would hope our counterparts in other nations consider the consequences of the impending situation. As this is a global problem it will require a global solution.

The CHAIRMAN. Thank you very much.

I think, as Senator Bond's interest emphasizes, this is not a regional matter. Every one of us, whatever region we come from in the country, has a stake in this.

Senator Boschwitz from Minnesota has joined us.

STATEMENT OF HON. RUDY BOSCHWITZ, A U.S. SENATOR FROM MINNESOTA

Senator BOSCHWITZ. Thank you, Mr. Chairman.

I, too, compliment you for holding this hearing and, indeed, stressing the importance of it by holding it in kind of the off-season. I might say that the hall is crowded with additional people who are seeking to get into this hearing. So the interest is, indeed, very high.

I have had all kinds of meetings about the greenhouse effect, including with some people here this morning, and I am this year on the UN delegation. I specifically joined the UN delegation for the purpose of speaking to the UN about global warming.

As a matter of fact, Mr. Chairman, the UN has now convened the Intergovernmental Panel on Climate Change, to address the problem. And I went to Geneva to address the first meeting of that panel about global warming. The panel is principally formed for the purpose of considering global warming because it is an issue, as you just pointed out, that affects not only Missouri, Vermont, or my State, but the world as a whole, and it is not going to be solved except through action of the world as a whole.

Interestingly, one of the aspects of the "decoupling" farm bill that Senator Boren and I introduced—in 1985, last session, and will reintroduce again in a new form this session—would in all probability result in the lower use of chemicals. At least it would not put a premium on the use of chemicals. It would have some environmental impacts that in the process of formulating the bill we did not fully anticipate. On ground water, it probably has an even larger impact than it does on the greenhouse effect, but the use of agricultural chemicals apparently does also have an impact on the atmosphere. So we would be getting some bonuses from that bill. Unfortunately, the bill is under some heavy attack by some folks on my side and yours. Yes, that is, I am afraid, the case.

The CHAIRMAN. The price of leadership, Rudy.

Senator BOSCHWITZ. That is what it is. That is what it is.

But, in any event, I am just very pleased that you have called for this hearing. It is an important hearing. Agriculture, forestry particularly, is going to be very, very involved in the solution to the problem. Reforestation is an important part of the slowing down of the greenhouse effect. I just compliment you, and I am pleased to be here.

The CHAIRMAN. Thank you very much.

Dr. Firor, why don't we start with you and then go to each member of the panel. Give us a summary of your statement, and then we will just open it up to questions for all three of you.

STATEMENT OF JOHN FIROR, DIRECTOR, ADVANCED STUDY PROGRAM, NATIONAL CENTER FOR ATMOSPHERIC RESEARCH, BOULDER, CO

Dr. FIROR. Thank you, Mr. Chairman.

My job here today is to give an overview of the scientific situation and make way for the other people who will talk more about particular impacts.

I was a little surprised to be invited to talk because every newspaper in the country has written long articles about the greenhouse effect some time during the past summer. So perhaps everything that needs to be said has been said. But another result of the long summer was that I was invited to talk all over the country on this topic, and I find from the questions asked that there are still many misconceptions around about the greenhouse effect. I will try to emphasize those areas where I think the public understanding can be improved by some straightforward statements.

Scientists have understood for a long time that there are some gases in the atmosphere—very, very small quantities but still important gases—that make life possible.

If I could have the first slide. We are going to need to kill that TV light, I think.

The CHAIRMAN. If we are going to show slides, can we kill some of these lights around?

Dr. FIROR. This is a simple diagram to show the effect we are talking about. Sunlight comes in, the red arrows on the left. Some of it is reflected away and has no particular influence on the Earth. But about half of it is absorbed and tends to heat the Earth. This heat must escape somehow, but the only way the Earth can lose heat is by radiating it away at long wavelengths, infrared radiation. And there the problem ensues, the effect ensues.

This radiation is absorbed by these very minor constituents of the atmosphere, less than one-tenth of 1 percent of the whole atmosphere, delaying this radiation from leaving the Earth, and thereby warming the Earth. This is a very large effect. If you could magically somehow remove this one-tenth of 1 percent of the gases that absorb infrared radiation, the Earth would be cooler by some 60 degrees Fahrenheit.

So the greenhouse effect is not some small effect that scientists, in order to worry everyone, have predicted. It is an essential feature of our atmosphere. It is an essential feature of life on Earth. The problem is we may get too much of a good thing. This one-tenth of 1 percent of the gases is now increasing rapidly in the atmosphere, and, hence, this heating is almost certain to increase at the same time.

I emphasize this point because I find in talking to the press and other groups that people regard the greenhouse effect as a new, somewhat esoteric, far-out effect, and we should wait a few years or a few decades to see if it is true. Well, it is true. It has been with us since time immemorial. We depend on it for our lives and our livelihood. And the question is not whether it is true; the question is: How much will it change with the ensuing change in greenhouse gases in the atmosphere?

The increase in these gases in the atmosphere is clearly connected with human activity. This is a diagram of how much carbon dioxide there is in the atmosphere and has been for several hundred years. These measurements come from bubbles that are trapped in ice in Greenland and Antarctica. This ice stores for us in a nicely measured way samples of air back almost as far back as you would care to look. We can dig up that ice; we can tell from what year it came and measure the composition of the air that was trapped.

We see that the amount of carbon dioxide, starting in 1750 in this group of measurements, began to increase quite rapidly and has been accelerating ever since. It is a very small fraction of the atmosphere. The scale on the left is parts per million of the atmosphere. So we are talking about a small constituent.

This rapid increase began, of course, at the same time that the Industrial Revolution got rolling. We discovered coal, later oil, other fossil fuels that place this gas in the atmosphere. We now have measurements that go back much further than this. If you trace this line back from 1750 to, say, 10,000 years ago, it is almost constant. So for a long time, there was a balance between those natural mechanisms—volcanos, hot springs and so forth—that put carbon dioxide into the atmosphere, and other mechanisms that remove it.

What we have done by adding to the sources and not adding to the ways of removing it, is unsettle that balance and produced this rapid increase.

Carbon dioxide is not the only gas. Methane, natural gas, has already doubled from its earlier value and is continuing to increase rapidly. Once again, measurements in the ice show that this was relatively constant for the last 10,000 years and then began to increase when enough people had enough influence to burn enough coal to raise the level throughout the entire atmosphere.

Senator BOSCHWITZ. That is not per million, though, is it?

Dr. FIROR. This occurs in even smaller quantities. That is parts per billion. So it is a very, very minor constituent of the atmosphere. It, however, is the second most important greenhouse gas and can change the climate of the Earth.

I emphasize human activities. Each of us contributes to this. The illustration I like now is: Your automobile, sir, if it is a typical American car, places 4 tons of carbon dioxide in the atmosphere each year.

The CHAIRMAN. Four tons?

Dr. FIROR. Four tons. Yes, sir.

The third major contributor to heat trapping is a pair of chlorofluorocarbons, the old spray-can gases, the same ones that stand accused of damaging the ozone layer high in the atmosphere. These synthetic gases are increasing very, very rapidly in the atmosphere, 10 times as rapidly as carbon dioxide. You will notice the scale there is parts per trillion by volume. We are talking about extremely minute quantities, yet here is a high leverage substance if we ever had one. The absorption is in exactly the right place in the spectrum to produce a maximum effect of heating the Earth.

How big will this climate change be? That is the question I am asked most frequently. This is a very difficult question to answer. This is a diagram put together some years ago by the National

Academy, showing the system we have to deal with. This is the climate system of the Earth. The atmosphere in the middle is influenced by sunlight coming in from above, ocean from below, pollution from all sides, mountains, ice. It is a very complex system, all of which is tied to all other parts of it.

We try to make this calculation by taking as much understanding as we have of the system, putting it together into the world's largest computer, and computing what the climate would be like if we increase these gases. This is a very difficult, time-consuming and expensive task, and there are only a few groups in the world capable of putting together such a complete numerical simulation of the climate so as to give some sort of answer as to how big will this climate change be. It is fortunate that we have more than one group because we can check each other, see what mistakes the other group made, and try to improve the whole business. It would probably good if there were a few more groups in the world attempting to do this calculation.

The models, these mathematical simulations, are today far from perfect. We are in midstream in the perfection of these models. They do not give answers to every question you might wish to ask. They differ somewhat in detail. There is, however, a strong consensus. All the models show a rapid heating of the climate if we continue to place these gases in the atmosphere. They show slightly different amounts, but they all show a heating. And this has resulted in the consensus that Senator Leahy referred to in the scientific community that, yes, these projections of a rapid climate heating must be listened to. They are warnings which are credible enough now to elicit some action.

I cannot answer the question I posed, though: How big will the climate change be? This depends on how long we continue to place these gases in the atmosphere. We quote numbers, and we have perhaps misled the community. We quote numbers that if you double carbon dioxide, it might be 3 degrees Celsius warmer. It is like being on an elevator. You might see the third floor as you go up, but the elevator is still rising. We will pass through 3 degrees on the way to 4 degrees, and 4 degrees on the way to 5 degrees if we continue to place these substances in the atmosphere in the quantities that we now do.

These calculations show that the climate warming should already be under way, and this is a bit of a controversial topic because the best data we can pull together show, indeed, the Earth has warmed in the last century. But we also know that in earlier centuries, the Earth has warmed and cooled by small amounts. So this is not absolute proof that the heating is under way.

It is a strong indication. And if you were to adopt the standard of evidence used, say, in civil suits—what is the preponderance of the evidence?—it would say yes, the climate heating is under way. If you wish for a stronger standard—beyond reasonable doubt—then we would have to say let us wait a few years and see.

This is a diagram prepared by Murray Mitchell, some 11 years ago, one of the greats in U.S. climatology. The top diagram is the one I wish you to regard. The band there on the left which he has drawn from 1850 to 2100 indicates the band of temperatures that the Earth's climate normally wanders within. The climate warms a

bit and cools a bit for reasons we do not fully understand. But we know it is not stable perfectly; it does wander in that fairly narrow band.

The change we are predicting is that split in the bands, one going off to higher temperatures and, if we did not place these gases, a continuation of the wandering. What this means is that a short period—10 years, 20 years—of a climate getting cooler is not evidence that this effect is wrong. We expect the climate to warm rapidly, cool, warm, and continue this wandering as it goes up this upper path.

I mention that because I have seen papers talking about the fact that North America cooled dramatically between 1940 and 1979, which, indeed, it did. This has no particular impact on our understanding of or evidence for rapid climate warming. It is the expected kind of behavior. The climate will in general warm, but there will be places that cool, there will be times that cool, in addition to the general trend, which will be upward.

Is this change big enough to worry about? The change which is projected by the models—the consensus value, let me call it—is the Earth's climate should warm about one-half degree Fahrenheit per decade. And that is very small. You and I, Mr. Chairman, cannot tell when this room warms a half-degree in 10 minutes, much less 10 years. So why should we worry about anything that small?

Let us look back at past climate changes to get some indication, some calibration of how a climate change affects us. This is, I am afraid, a hand-drawn diagram I put together a few weeks ago, showing climates as deduced for the last 1,000 years. We see that measurements made in two places, Europe and California, agree pretty much, although in the early part of the period the climates may have been different. The climate wandered by a half-degree Celsius, say 1 degree Fahrenheit, during this period. Yet these periods are chronologically very exciting: that warm period back in the 11th and 12th century and the so-called "Little Ice Age," which had two episodes more recently.

These episodes characterized by small numbers, 1 degree Fahrenheit, produced rather major changes in agricultural practices throughout Europe. One can now trace where farmers changed which crops they planted. They changed how high up a hillside they would plant in response to this relatively small change.

Marginal societies—for example, the colonies around the edge of Greenland—were destroyed by that cooling. The grass they depended on to graze cattle went away, and the cattle went away, and the colonies went away. So a half-degree or 1 degree is, in fact, a sizable climate change.

The climate change we are talking about is five times as fast as these historical ones which produced measurable effects.

Go back further, 10,000, 12,000 years ago as we came out of the last Ice Age. This change went on over thousands of years. It was a large change, several degrees; it occurred very slowly. Once again, the change we are talking about will occur 5 or 10 times as fast as this change. This change completely rearranged the face of North America. Tree species had to migrate dramatically in order to keep up with climates that they survived in. The sugar maples that you mentioned moved in as this climate changed.

What kind of climate change should we expect in every region on Earth? Here we are getting somewhat beyond the capability of present calculations. We know that the polar regions will warm more rapidly than the equatorial regions. We suspect that the centers of continents will become drier; for example, the midwestern United States. We suspect winters will warm more than summers. But beyond that, the calculations are not capable today of giving good answers.

We can put some limits on it. We can develop scenarios of climate which we say are physically reasonable and, hence, can be used to analyze the impacts. But we cannot answer the question that we are asked most often: What will happen right here at this location?

Is there anything we can do about this? I notice there is a certain tendency for people to say this is such a big problem we cannot tackle it. I do believe, Mr. Chairman, that, in fact, there are things we can do about it. We can slow down the rate at which we put these gases in the atmosphere and slow this climate change to give us a fighting chance to adapt to it in a reasonable and noncrisis mode.

Thank you.

[The prepared statement and attachments of Dr. Firor follow:]

STATEMENT OF DR. JOHN FIROR, DIRECTOR, ADVANCED STUDY PROGRAM, NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

Mr. Chairman: I appreciate the opportunity to present to you an overview of the global warming issue. During the past hot, dry summer almost every newspaper, magazine, tv and radio station discussed the hot weather and its possible connection with the greenhouse effect, so one might think that all of the basic facts are well understood by everyone. But as I give talks around the country and answer questions from reporters and others, I am frequently reminded that there are still gaps in the public understanding of this problem, and many misconceptions, so I am pleased to join in these hearings and attempt to share with you what my colleagues and I have learned about this issue.

I believe that each of you is familiar with the broad outline of this problem. Scientists have understood for a long time that life on earth depends on certain gases which appear in the air in very small concentrations. These gases absorb heat, or infrared radiation, that would otherwise escape from the atmosphere. They thereby warm the surface of the earth and keep it livable. The problem arises because the amount of these gases in the air is now increasing rapidly, and we are faced with having too much of a good thing -- a hotter earth than we are prepared to live with. I state the problem this way because news reports frequently picture the greenhouse effect as a new and controversial phenomenon, and imply that we need to wait some years or decades to "see if it is true". Actually the greenhouse effect is one of the better understood features of the atmosphere and climate; it has always been with us; and we depend on it to keep the earth from being ice-covered and uninhabitable.

The reason that we are getting too much of a good thing is that infrared-absorbing gases are being placed in the air by various human activities, and there are today so many of us that our activities can change the whole earth. For example, the most important heat-trapping gas is carbon dioxide, and the increase in that gas in the atmosphere is the result of the burning of fossil fuel and, to a lesser extent, of the replacement of forests with grasslands or other use. Thus millions of individual actions around the world, guided by international economic forces, government regulations, and corporate policies, add up to a changing composition of the air. Your automobile, if it is an average American car, places four tons of carbon dioxide in the air each year.

The other heat-trapping gases are similarly related to what we do. The second most important greenhouse gas is methane. Some of this gas leaks to the air from coal mines and pipelines, but most of it comes from anywhere that organic material decays without an abundance of oxygen -- in municipal waste dumps, rice paddies, and the intestines of cattle and termites. Both of these gases -- carbon dioxide and methane -- have large sources that have nothing to do with people, and equally large processes that remove them from the air, maintaining an approximate balance over long periods of time. What we are doing is adding a new source that is not balanced, thereby increasing the amount in the air each year.

The third major contributor to heat trapping is the pair of chlorofluorocarbons -- CFC-11 and CFC-12 -- the same gases that stand accused of damaging the ozone layer high in the atmosphere.

These gases are powerful infrared absorbers, they are completely synthetic, there are no sources other than human industrial activity, and the amount in the air is doubling about every 15 years. There is a long list of other heat-trapping gases now on the rise, but these four adequately represent the problem. Let me go over the questions that I am asked most frequently and which sometimes arise from misconceptions about the problem.

How big will this climate change be?

Scientists attempting to project future climates use as their tool numerical simulations, or numerical models, of the climate. They put together as much of their detailed understanding of the the earth's climate as they can fit into the world's largest computers, and they calculate what the climate will be like with more heat-trapping gases in the air. This is a difficult and expensive task, and only a few scientific groups on earth have the size, expertise, patience, and computing power to attempt such calculations. The models they have constructed differ one from the other in mathematical detail, in the relative emphasis of the various physical processes included in the model, and in the manner in which the atmosphere itself is represented. It is fortunate that we have at least a few, quite different, models, since comparing different approaches can teach us how to improve all of the calculations. These models today are far from perfect, their results differ in many details. But they all agree in showing that the continued increase in greenhouse gases in the atmosphere will result in a rapid heating of the earth's surface, and it is this agreement that has led to a broad scientific consensus that the projections of a warmer climate should be taken seriously. A recent scientific review of all the evidence reported that the rate of heating, when all of the effects known that might delay the change have been included, is about one-half degree fahrenheit per decade. This estimate assumes that the world will take a business-as-usual approach to fossil fuel use and to other sources of greenhouse gas emissions. The question as usually asked -- how big will the climate change be? -- cannot be answered until we have some guess as to when the world's countries might taper off their emissions of greenhouse gases.

The calculations of the climate models say that the warming should already be underway. Determining whether this has indeed happened is difficult, since the year-to-year and decade-to-decade fluctuations in climate are so large. But the scientific groups that have laboriously assembled measurements for the last century from locations around the globe have all shown a heating of about the expected magnitude. I am sure that you have heard during the past summer some controversy over whether we have already observed the beginning of the warming. The controversy is less than it might seem; it mostly has to do with standards of proof. If you were to ask what the "preponderance of the evidence" shows, most experts would say "yes, the heating has begun". If you require the stiffer standard of "beyond reasonable doubt", most of us would say "let's wait a few years and see."

Are these changes large enough to worry about?

One-half degree per decade sounds small; should we be worried? In considering what the impact of this projected change will be, we can look at climate changes in the past and see what impact they

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had. During the last 1000 years the earth has been warmer, around the 11th Century, and colder during the "Little Ice Age" a few centuries ago. It is estimated that each of these represented a widespread -- perhaps global -- change in average temperature of about 1 degree F. These changes appeared and disappeared at rates of about 0.1 degree F per decade. These apparently small changes forced shifts in agricultural practices, migrations of peoples, and resulted in the destruction of marginal societies. The global change projected for the coming decades is five times as fast as these earlier events, and if allowed to continue until late in the next century, will be five times as large. American agriculture is flexible and innovative, and many steps can be envisioned that will prepare for this steady change to be added to the the large year-to-year weather variations that we now contend with. A continuous stream of new crops can be developed; irrigation systems can be built where dryer climates will prevail, and water brought, in steadily increasing quantities, from wherever it is available; pest management strategies can be devised to deal with those warm climate insects and diseases that will extend their range. But, all together, steps equivalent to moving the farm 5 miles north each decade cannot be considered easy, inexpensive, or desirable.

Going back even earlier we can examine the retreat of the last ice age over 10 thousand years ago. Little is known about the impact on the people of that time, although the disappearance of most of the large mammals from this continent must have induced large changes in hunting patterns. But we can more definitely trace the forests of North America from the pollen grains they left behind. The warming over thousands of years, at global rates even slower than those during the last 1000 years, forced major shifts of the forests. Before the warming spruce was a common species in what is today Ohio. This kind of tree is now centered in Northern Quebec, while oak that was in South Carolina now occupies Ohio. The rates of movement of these tree species were surprisingly fast, a few hundred yards a year. Forest experts are quite doubtful that these and other tree species can move five or ten times as fast as they did at the end of the last ice age. There are many other details we can draw from the earlier times, but even these examples give the answer to our question. Yes, the projected change is large enough to worry about.

What kind of changes can be expected in each region on earth?

The various models agree on the general distribution of the climate heating. They foresee that in the Northern Hemisphere the polar regions will warm more rapidly than the average and the equatorial region more slowly, with our country in between. And they project that winters will warm more than summers. For considering impacts on crops and forests we need information on precipitation as well as temperature, and here the models are considerably less certain. There are indications that the centers of mid-latitude continents, for example the U.S. Midwest, will have less soil moisture during the growing season than they do today. Increased evaporation that will accompany higher temperatures could decrease the average flow in some river basins. One effect that will be truly global will be the rise in sea level -- averaging two inches per decade or more. But considerable scientific progress will need to be made before we can confidently and comprehensively answer the most

frequent question we are asked: What will it be like where I live, or where I farm, or in my congressional district?

Is there anything that should be done now?

A few months ago, the government of Canada organized, in Toronto, a meeting of experts on climate change, energy, agriculture, and related topics, to discuss "The Changing Atmosphere: Implications for Global Security." More than 300 scientists and policy makers from 46 countries participated. The report of this conference, after speaking of "harmful consequences", "a major threat to international security," and "potentially severe economic and social dislocations," states flatly: "It is imperative to act now."

This last statement arose from the judgement of the participants that to give ourselves a fighting chance to adapt to the coming changes we must also slow them down, that the projected rates are too large to allow for a planned and economical adaptation. The participants were well aware that some heating is inevitable -- we have already put large quantities of heat-trapping gases in the air and will surely put more. But they were also aware that slowing the change is well within the capability of our technology. A treaty has already been negotiated that will reduce production of the CFC's, and readily available techniques are waiting to be used to reduce sharply our use of fossil fuels -- techniques that let us use fuel more efficiently and hence get our work and play done with less damage to the climate. The Toronto report suggest a goal of a 20 percent reduction of carbon dioxide emission by the year 2005 -- a goal which studies show to be not only technically feasible but economically advantageous as well. I do not pretend that meeting this goal is politically easy, only that for once we do not need to wait on some engineering or scientific breakthrough. The equipment is there; we do not need further improvements in photovoltaic cells; we do not need new nuclear plants; we do not need ocean thermal generators or space energy collectors. We just need to use the high mile-per-gallon cars, the best new light bulbs, good building insulation, efficient refrigerators and furnaces, combined cycle power plants, and other technology that is already available. In the longer run, as we near the end of efficiency improvements to exploit, we will need to examine many other -- and more difficult -- steps to work toward stabilizing the composition of the atmosphere. But the first step is already clear.

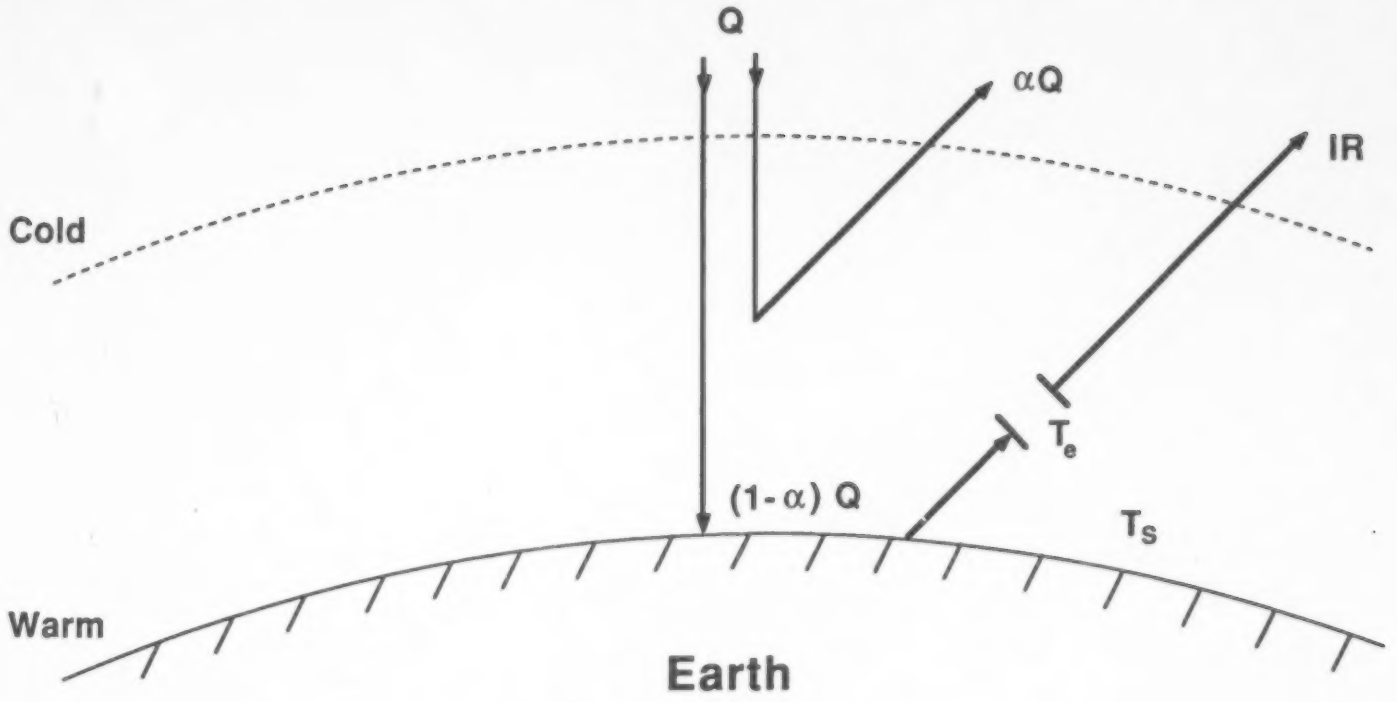
In summary:

- There is a strong scientific consensus today that the climate will soon warm at a rate exceeding any seen by human civilizations.

- These changes will have major impacts on agriculture, and could devastate unmanaged forests.

- These changes will be fast enough to make adaptation difficult and expensive.

- There is a need for prompt steps to reduce emissions of heat-trapping gases, especially carbon dioxide.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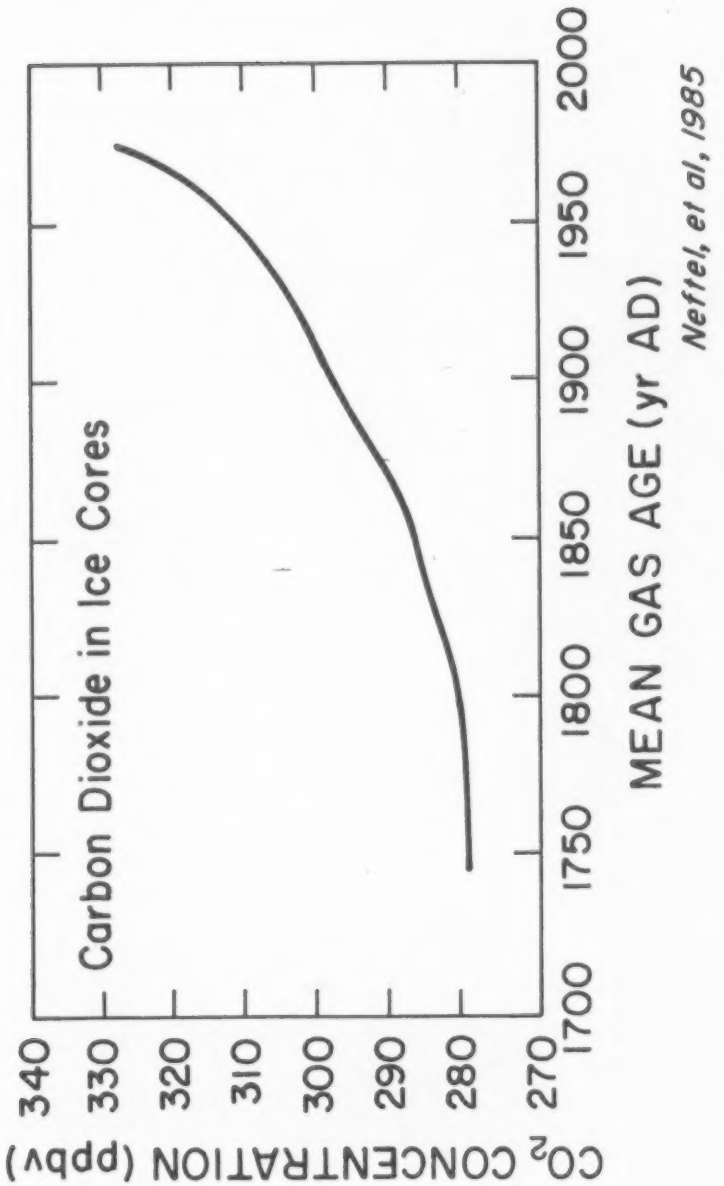
Carbon Dioxide in Ice Cores
CO_2 CONCENTRATION (ppbv)
340
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310
300
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270
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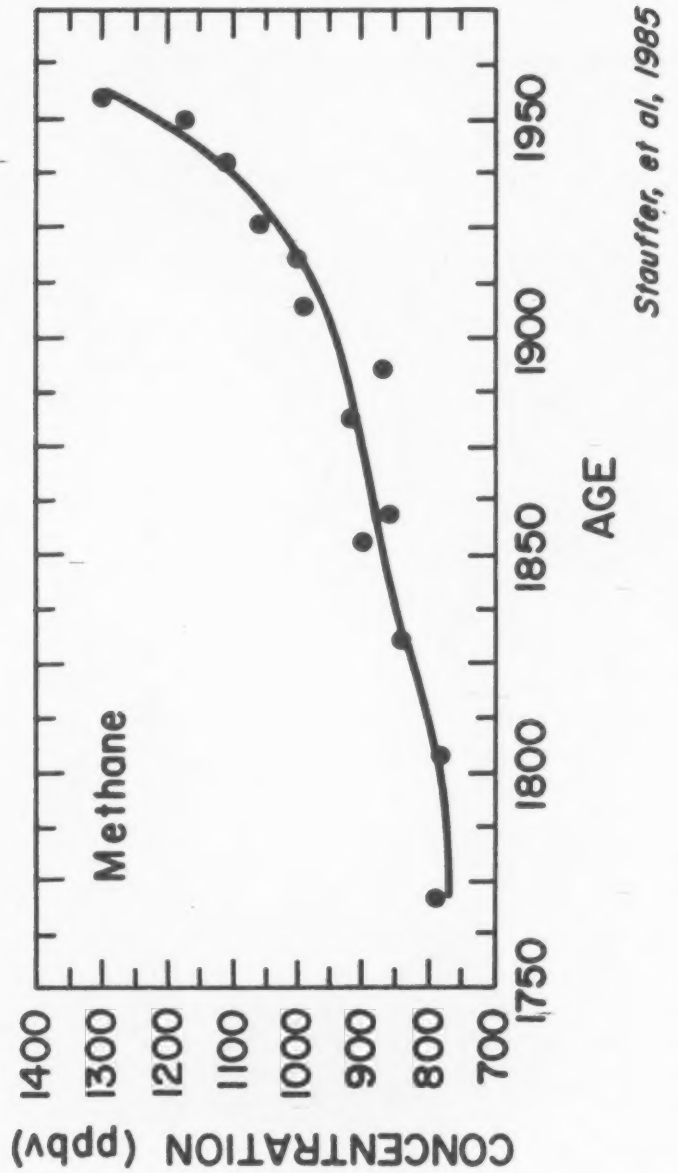
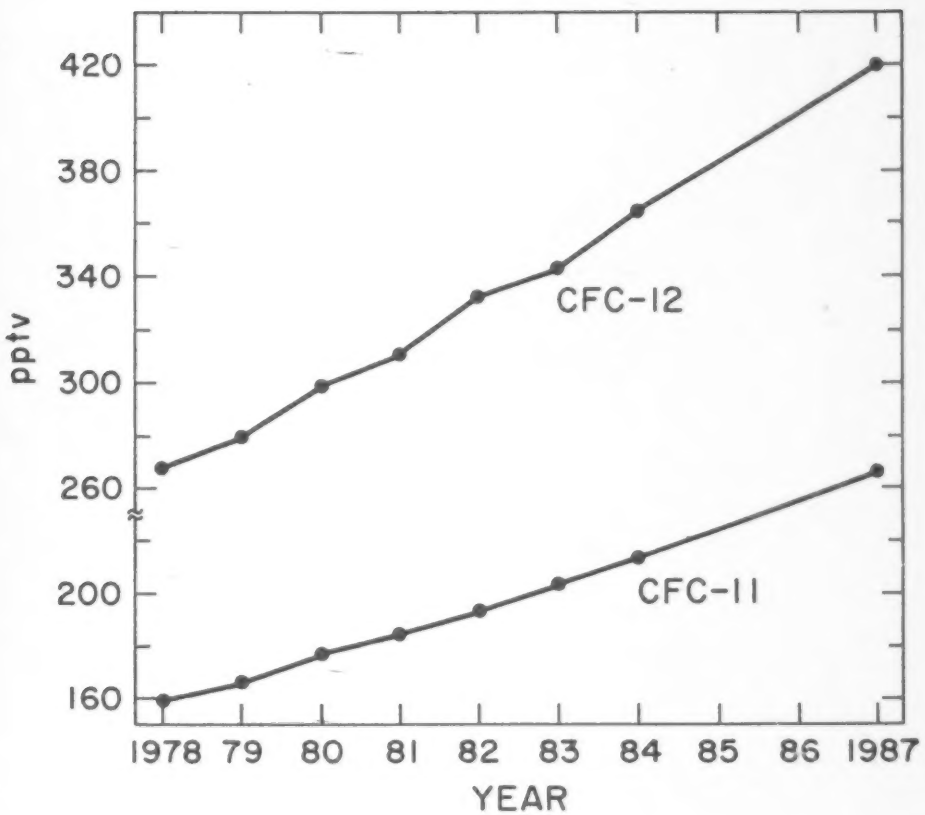
1800
1850
1900
1950
2000
MEAN GAS AGE (yr AD)
Neftel, et al, 1985



Stauffer, et al, 1985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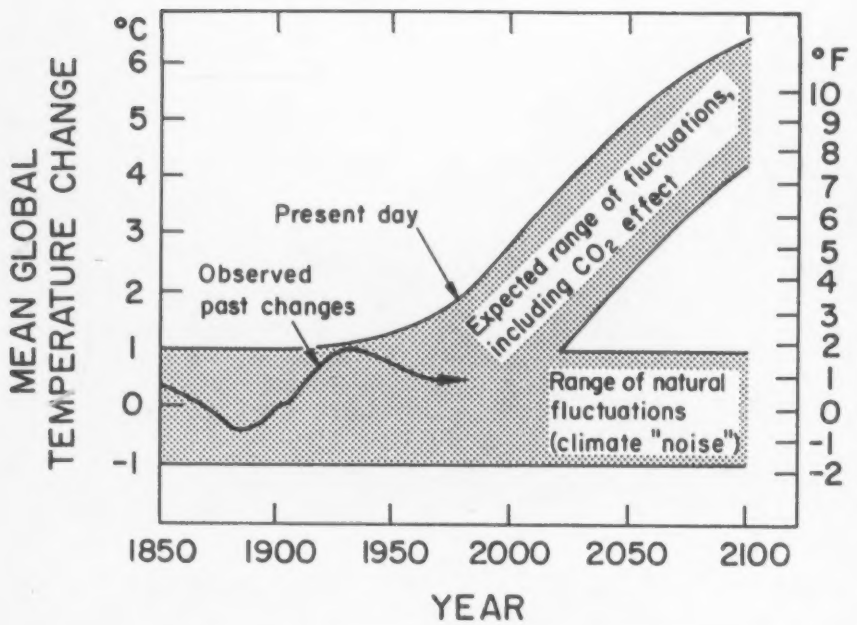
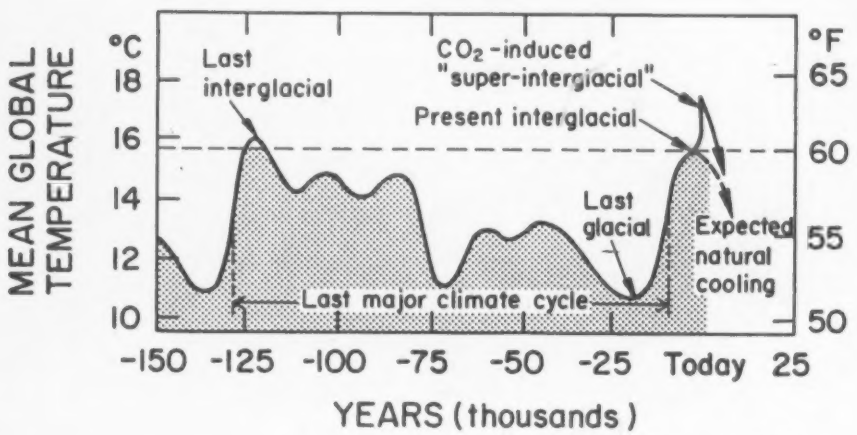
YEAR





Mitchell, 1977

RELATIVE TEMPERATURE (°C)
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1800
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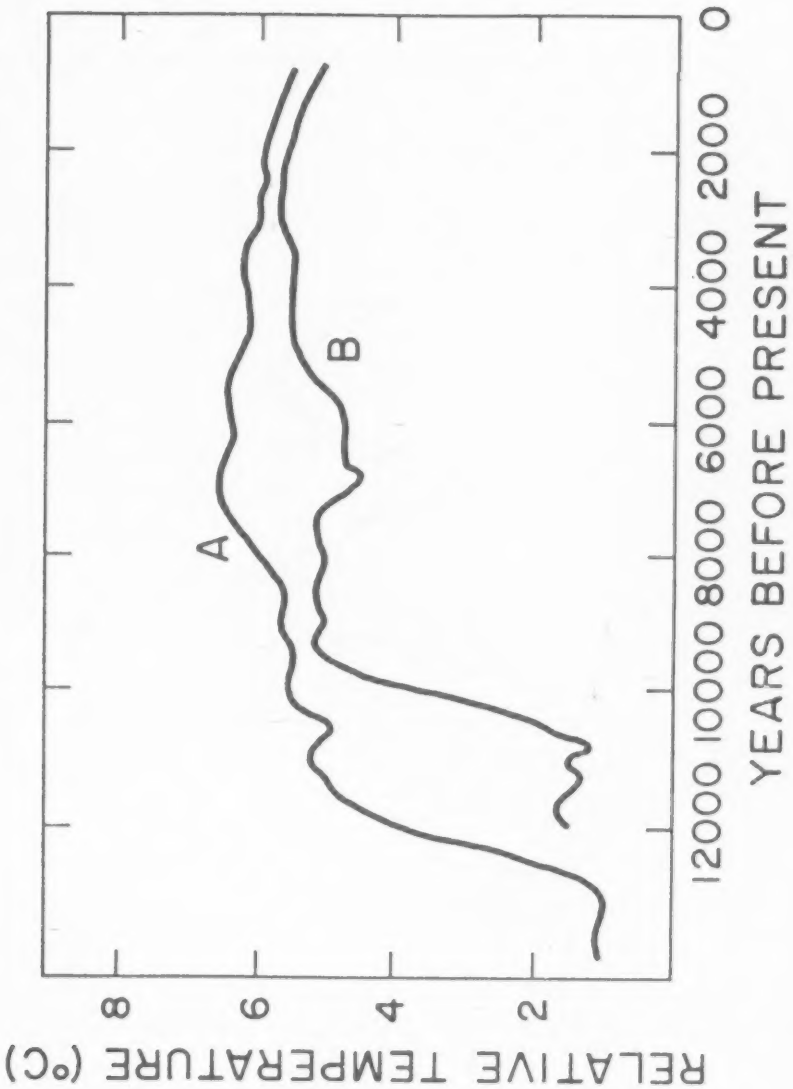
YEAR
A
B


RELATIVE TEMPERATURE (°C)
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6
4
2
A
B
12000 10000 8000 6000 4000 2000 0
YEARS BEFORE PRESENT

The CHAIRMAN. Thank you.

Senator Boschwitz.

Senator BOSCHWITZ. What is "Minnesota pollen"?

The CHAIRMAN. This is another problem we get from Minnesota, between the Ice Age and the Minnesotans.

Senator BOSCHWITZ. He wants the Ice Age instead of the Minnesota pollen.

Dr. FIROR. For temperatures before the invention of the thermometer, we have to deduce it from other evidence. One can find pollen grains deposited in bogs in Minnesota and elsewhere which are characteristic of plants. We know what temperatures those plants grow at. So by analyzing the plant distribution year by year or century by century or thousand years by a thousand years, we can say what the rough temperature was in that region that encouraged those plants.

This is a technique that is widely used to say something about earlier climates on Earth.

The CHAIRMAN. You can put the lights back on unless, Ms. Rosenzweig, you are going to need the lights off.

Ms. ROSENZWEIG. I have charts.

The CHAIRMAN. You have charts.

Ms. Rosenzweig is at Columbia University, Department of Geography, and NASA/Goddard Institute for Space Studies. She is an agronomist. She coordinated the EPA report chapter on the potential effects of global climate change on agriculture. It is kind of a good news/bad news thing as I read it, and I am greatly oversimplifying it. You said even if global warming occurs, the good news is we probably will not starve here in this country. The bad news is that exports may decline significantly; from an economic point of view, that could be extremely bad news to this country. With our trade deficits, the one bright light in it has been agricultural exports.

Doctor, why don't you describe your study and the findings of your study?

Senator BOSCHWITZ. I am going to get off this committee if that happens.

The CHAIRMAN. What is that?

Senator BOSCHWITZ. If agriculture exports decline significantly because of global warming.

The CHAIRMAN. And blame it on me?

Senator BOSCHWITZ. Absolutely. [Laughter.]

The CHAIRMAN. Go ahead, Doctor.

STATEMENT OF CYNTHIA E. ROSENZWEIG, RESEARCH SCIENTIST, DEPARTMENT OF GEOGRAPHY, COLUMBIA UNIVERSITY, NASA/GODDARD INSTITUTE FOR SPACE STUDIES, NEW YORK, NY

Ms. ROSENZWEIG. Mr. Chairman, members of the committee, for the past year-and-a-half, I have been coordinating a set of agricultural studies on the potential impacts of climate change on U.S. agriculture. These studies were organized for the Environmental Protection Agency's report to Congress on "The Potential Effects of Global Climate Change on the United States." The report is cur-

rently in draft form and is undergoing scientific and interagency review. I would like to share with you today the preliminary findings and the relevant implications of the results.

As Senator Leahy said in his introduction, climate and weather have been and continue to be dominant factors in agricultural productivity. We have only to compare the Dust Bowl years of the 1930's, when wheat and corn yields dropped by up to 50 percent, and this past summer of 1988, when the Nation's corn crop decreased by almost 40 percent, to see that American agriculture is still vulnerable to extreme climatic events.

Now, as Dr. Firor has just explained to us, atmospheric scientists are projecting temperature increases in the next century to levels higher than any in at least the past 150,000 years. Associated changes in rainfall and other hydrological variables are also projected, although these are less certain. Although the climate projections are uncertain, especially in regard to the rate of change and regional specificity, the magnitude of these projections creates the need for a broad consideration of the impacts of potential climate change on U.S. agriculture.

Recognizing this need, Congress sent a formal request to the EPA administrator to undertake a study of the potential health and environmental effects of the projected climate change, including the potential impacts on agriculture.

Among the key questions in estimating the agricultural impacts of climate change are: Will the United States be able to produce enough food to feed its population? What changes would occur on a regional and local level? Will farmers be able to adapt to these changes?

Another critical issue in agriculture is the role of carbon dioxide itself. Not only does carbon dioxide warm the atmosphere, it also increases the growth of crops through its effect on photosynthesis. There are major differences in the research community about the extent to which these beneficial effects of CO_2 on crop growth will balance the negative effects of the climate change.

The EPA studies sought to answer these questions. The Environmental Protection Agency, in order to do this, developed a set of climate change scenarios based on several global climate models that Dr. Firor described. These scenarios were used in a set of studies, both modeling studies, literature reviews, and analysis. These studies were carried out by university scientists and also scientists from Federal agencies, and they covered the following research areas:

We looked at potential effects of climate change on crop growth and yield; regional and national agricultural economics; the demand for irrigation water; water quality; pest-plant interactions, and how those may change with the potential climate change; what are the direct effects of CO_2 on crop growth and yield; the impacts of extreme events; potential farm level adjustments, what farmers may be able to do; livestock pests and disease because livestock is an important part of agriculture; and agricultural policy.

These studies are a first step in linking the output from the global climate models with models of the agricultural system. The results are not predictions of what will happen to American agri-

culture. Rather, they are explorations of the sensitivities of our system to these levels of potential changes.

The sources of uncertainties are many. First, we have the uncertainties due to the climate projections, as Dr. Firor described. Then we have uncertainties added to that from all the assumptions used in the agricultural studies.

For example, in the crop modeling studies, the climate scenarios did not include changes in interannual variability. For example——

Senator BOSCHWITZ. In what?

The CHAIRMAN. Yes, you went by me on that one, too.

Ms. ROSENZWEIG. This means that the frequencies of drought—for example, the number of years of drought—are not changed in the climate change scenarios that were developed.

Senator BOSCHWITZ. What did you call it?

The CHAIRMAN. What is the term?

Ms. ROSENZWEIG. Interannual variability.

Senator BOSCHWITZ. Oh, OK. I see it here.

Ms. ROSENZWEIG. If the frequencies of drought change, these obviously could affect crop yields significantly.

Another source of uncertainty in the studies is that we were not able to explore the full range of adaptation mechanisms that farmers may adopt. For example, we were not able to include changes in crop species or crop types to see, as the climate changes, what the farmers may switch to in terms of their crop types.

Now I would like to review the major findings, and I brought some charts which show these.

This chart shows the percent change in dryland corn yield with one climate change scenario, and this included the direct effects of CO_2 on crop growth. We see that in different regions of the country we have different changes in crop yields. In the Southeast, the corn yields decreased with this climate change scenario from 60 to 90 percent. But in northern areas, up in, for example, Minnesota and Michigan, there were increases of the corn yields from 0 to 30 percent. These northern increases are due to lengthening of the growing seasons in those northern areas, and the climate actually becomes more favorable for crop growth in that scenario.

Now, results from crop yield studies such as these were then put into an agricultural——

Senator BOSCHWITZ. What are the shaded areas? What is the crop yield in Iowa, Nebraska and Kansas?

Ms. ROSENZWEIG. That is minus 60 to minus 30.

Senator BOSCHWITZ. Oh, minus 30 to minus 60.

Ms. ROSENZWEIG. Right. Minus 30 to minus 60.

Senator BOND. How does Texas go up, increase; whereas, the Southeastern States are decreasing?

The CHAIRMAN. You have a good question.

Ms. ROSENZWEIG. This shows that in each region of the country, depending on the climate that is there now and the projection of the climate change, you can get differential results from region to region. When these different regional changes are put into the economic model, we see that the projected climate change does not threaten food supply for the Nation. There is enough food, even under the most extreme climate change scenario.

But we do find regional changes in comparative advantage of the different regions. And so how agriculture is carried out around the country may change.

Senator BOND. I was particularly interested in the difference between Texas and the Southeast. One would think that if the warming in the Southeast makes corn a less viable crop there, it would have the same impact on Texas. But it is obviously the opposite effect, from your chart.

Ms. ROSENZWEIG. That is correct. That is because in the Southeast—let us put it back up again. In the Southeast, that particular climate change scenario had very severe climate change for the Southeast. The climate change scenarios were specific from region to region, according to the climate model outputs. So this is one example that we could have decreases in the Southeast and another area, for example, in the Great Plains, do better.

Senator BOSCHWITZ. I meant to note while the chairman was here that you indicate that global warming will have no impact on Vermont. [Laughter.]

He has only a few dairy cows roaming around. With the Bush administration coming in, Texas gets everything these days. [Laughter.]

They can do no wrong down there.

Ms. ROSENZWEIG. When we took a set of results from these crop yield studies and put them into the economic model, the results implied that the projected climate change does not threaten food supply for the Nation, even under the most extreme of the climate scenarios.

Senator BOSCHWITZ. Would you say that again, please?

Ms. ROSENZWEIG. The results of the EPA studies imply that the projected climate change does not threaten food supply for the Nation. There was enough production capacity in the United States to satisfy demand, even under the most extreme climate change scenario that we looked at.

However, the projections also showed that in some scenarios, particularly in the most extreme scenario, U.S. exports did decline significantly.

Now, it is important to note that climate change may expand or limit agricultural production in other areas of the world. Our study did not look at how other areas of the world may change. Changes in U.S. agriculture will take place in this global context, and the overall result could be changes in the whole pattern of global food trade. And the demand for U.S. exports may be altered.

If our current understanding of the global climate warming is qualitatively correct, agricultural land in more southern latitudes may go out of production, while agricultural acreage appears likely to expand in the north. This chart shows regional agricultural land use change and the percentage of change for four different scenarios.

The direction of results show that in the southern areas, agricultural land decreases. In the northern areas, you get slight increases in agricultural land use. Now, this is only the amount of acreage in agricultural crops, and the results show that productivity, when you look at the yields that are occurring in the northern section

with our results, they show increases in productivity in the north as well.

These regional changes in agriculture have important implications for rural communities. The industry of agriculture, as you know, is composed of many people besides farmers. And it may be that things such as markets, transportation networks, et cetera, may need to change in response to these types of regional shifts.

Other regional changes may also occur. The next graph shows the present and potential overwintering range of the potato leafhopper. This is a major pest of soybeans. When the entomologists who did this study looked at where the insect overwinters, they found an expansion northward with the climate change scenarios.

Now, the importance of this is that where the pests overwinter determines how far north they can extend into the cropping areas in the summer. So that we found that infestations of pests may extend northward and also may be more severe.

We found similar results when we looked at ranges of livestock pests and diseases also.

Senator BOSCHWITZ. Ms. Rosenzweig, you may be getting into greater detail at this point than we are able to handle at this first hearing. So if I may, I would like to ask you to conclude.

Ms. ROSENZWEIG. Surely.

Just let me show the last major point, which is that regional irrigated acreage may also increase. The economic model also included irrigated acreage, and we find in every irrigated region of the country an increase in irrigated acreage.

Now, this does not necessarily mean that the irrigation acreage will increase, but it implies that there will be a demand, an increase in the demand by the agricultural sector for more irrigation water.

To conclude, while many critical uncertainties remain about the magnitude and timing of impacts, it appears that climate change is likely to affect agriculture and rural communities in the United States significantly in the coming century.

The initial analysis of climate change impacts on U.S. agriculture provided by the EPA studies indicates that concern for our major resources, especially land and water, rural communities and the environment appears justified.

Thank you.

[The prepared statement and attachments of Ms. Rosenzweig follow:]

STATEMENT OF CYNTHIA E. ROSENZWEIG,
DEPARTMENT OF GEOGRAPHY, COLUMBIA UNIVERSITY

Mr. Chairman, members of the Committee, as coordinator of the agricultural studies done for the U.S. Environmental Protection Agency's Report to Congress on The Potential Effects of Global Climate Change on the United States, I would like to share with you the preliminary findings and relevant implications of the results.

The studies completed for the EPA report are a first step in linking models of climate change to models of agricultural impacts. They were designed to help define the potential scale of climate change impacts on U.S. agriculture. While the studies represent the most comprehensive analysis, to date, of these potential impacts, the findings are initial projections of the sensitivity of American agriculture to the estimated climatic changes, rather than predictions of what will occur. The EPA report is currently in draft form and undergoing scientific and interagency review.

Given global climate change, the main conclusions that may be drawn from the EPA studies are: (1) U.S. food supply appears to be sufficient to meet domestic needs, but export levels could decrease, (2) significant regional shifts in agricultural production are likely, (3) demand for water for irrigation is estimated to rise in many regions of the country, and (4) the extent to which the direct effects of CO_2 will be beneficial is uncertain.

Before providing the details of the EPA analysis, it is important to note that climate and weather have been and continue to be dominant factors in agricultural productivity, despite technological advances such as improved hybrids and the widespread use of chemical fertilizer. We have only to compare the Dust Bowl years of the 1930s when wheat and corn yields dropped by up to 50% and the summer of 1988 when the nation's corn crop decreased by almost 40% to see that American agriculture is still vulnerable to extreme climatic events.

Atmospheric scientists are now projecting temperature increases by early in the next century to levels higher than any in at least the past 150,000 years. Associated alterations in rainfall and soil moisture are also expected, but these predictions are less well defined. Although the climate projections are uncertain, especially in regard to the rate of change and regional specificity, their magnitude creates the need for a broad consideration of the impacts of potential climate change on U.S. agriculture.

Recognizing this need, Congress sent a formal request to the EPA Administrator in 1986 to undertake a study of the potential health and environmental effects of climate change, including the potential impacts on agriculture.

In order to carry out the Congressional request, EPA developed a set of climate change scenarios based on global climate model output for doubled levels of atmospheric CO_2. EPA selected the results of several different climate models in order to explore a broad range of future climates. These scenarios were used in models of agricultural systems to determine the potential effects of climate change. The studies involved the following research areas, either regionally or nationally: 1) crop growth and yield; 2) regional and national agricultural economics; 3) demand for irrigation water; 4) water quality; 5) pest-plant interactions; 6) direct effects of CO_2 on crop growth and yield; 7) impacts of extreme events; 8) potential farm-level adjustments; 9) livestock

pests and diseases; and 10) agricultural policy.

Among the key questions in estimating the agricultural impacts of climate change are: Will the U.S. be able to produce enough food to feed its population in the future? What changes will occur on a regional and local level? and Will farmers be able to adapt? The EPA studies sought to answer these questions.

Another critical issue is the role of CO_2 itself. Besides acting as a greenhouse gas and warming the atmosphere, increased levels of CO_2 also increase crop growth and improve water use in plants. There are major differences of opinion in the research community about the extent to which the beneficial effects of increasing CO_2 will mitigate negative climate change effects on agriculture. What will the magnitude of the positive effects be in relation to the predicted climate changes? Will the direct effects mitigate or overcome the climate effects? Several modeling studies undertaken for the EPA report addressed this issue; they examined both direct physiological effects and climatic effects of carbon dioxide simultaneously.

Simulated regional changes in crop yields and hydrology were then used in a national agricultural economics model to estimate regional and national changes in crop production, land use, and demand for irrigation. Such a coordinated analytical framework is necessary in order to account for the effects of market forces on the total agricultural system, including livestock, and to evaluate the adequacy of the nation's resource base for agricultural production.

The sources of uncertainty are many. The climate scenarios did not include changes in interannual variability, such as changes in the frequencies of drought or storms, even though these could affect crop yields significantly. The climate models have not yet been validated to project these types of changes. The effects of changes in levels of tropospheric and stratospheric ozone on crops were not considered, nor were changes in levels of pest infestations. The crop models, while among the best now available for large-area studies, are simplistic, and may not provide correct estimates for the extreme climatic conditions created by the climate change scenarios. The crop models can only approximate the physiological effects of CO_2 on crop growth and water use at this time. Finally, the range of possible alternative cropping strategies was not fully explored in the studies, such as substitution of different crop species, nor were potential changes in foreign demand for U.S. agricultural commodities.

Now, let me review the conclusions in further detail.

1. <u>U.S. food supply appears to be sufficient to meet domestic needs, but export levels could decrease</u>. The EPA studies imply that the projected climate change does not threaten food supply for the nation, even under more extreme climate scenarios. Production capacity of U.S. agriculture appears to be adequate to meet domestic needs.

Model projections done for the EPA report show that U.S. exports may decline significantly, based on a study in which the demand for exports did not change. It is important to note that climate change may expand or limit agricultural production in other areas of the world, and that changes in U.S. agriculture will take place in this global context. The overall result could be changes in the patterns of global food trade, in particular the demand for U.S. exports.

We also examined the effects of improvements in productivity caused by future technology and the impact of increased population demand for food, along with climate change. In this situation, continued advances in U.S. agricultural technology equal to those that have occurred over recent decades would be necessary to offset the negative effects of climate warming. Another way of saying this is that improvements in production are likely to be small despite new technologies if climate change occurs. This suggests the need to maintain a strong agricultural research program in the United States.

2. Significant regional shifts in agricultural production are likely. If the current understanding of global climate warming is qualitatively correct, agricultural land in more southern latitudes may go out of production, while agricultural acreage is likely to expand in the north, as shown in Fig. 1. All climate change scenarios tested show that the southern areas of the United States become less productive relative to northern areas. This is primarily because the high temperatures predicted for climate change will stress crop production more in southern areas than in northern areas where crops are currently limited by lower temperatures and shorter growing seasons. The lack of fertile agricultural soils in northern areas may limit this expansion. Fig. 2 shows yield changes in soybeans for one climate change scenario.

Other potential changes likely to occur include changes in infestations of crop pests, altered ranges of livestock pests and diseases, and higher levels of heat stress on livestock. For example, a northward extension of crop pest ranges and increased pest populations may reduce yields and affect livestock (Fig. 3). Warmer temperatures may result in northward extension of the range of diseases and pests that now afflict livestock in the south, and could make conditions more favorable for introduction of new livestock diseases into the southern United States. These effects are all driven in large part by high temperatures.

As climate changes, farmers are likely to adapt with alterations in management practices, such as earlier planting dates, crop types and varieties appropriate to the new climatic regimes, and development of irrigation systems. If climate change is not severe, these adjustments may mitigate losses in crop yields. More severe climate change is likely to make adaptations more difficult and more costly, with increased likelihood that farms would be abandoned.

Regional changes in agriculture have important implications for rural communities. The industry of agriculture is composed of many people besides farmers, such as, farm equipment manufacturers, fertilizer and seed suppliers, and rural bankers, to name but a few. As production areas shift, climate change effects will reverberate through this larger community and are likely to result in structural changes in local economies such as relocation of markets and transportation networks. At its most extreme, climate change could cause dislocation of rural communities through farm abandonment.

Natural environments may also suffer because of these changes in agriculture due to greater need for pesticides, the potential for increased soil erosion, and loss of wildlife habitats. Shifts in regional production patterns imply changes in ground and surface water pollution, and chemical pesticide usage may change to control both crop and livestock pests. Thus, climate change could

exacerbate many of the current trends in environmental pollution and could initiate new ones.

3. Demand for water for irrigation may rise. Demand for water for irrigation is likely to rise with warmer temperatures. Fig. 4 shows that irrigated acreage is projected to rise with climate change. Increased demand for irrigation occurs for a number of reasons. First, crops need more water when grown in higher temperatures. Second, farmers are likely to respond by irrigating in order to ensure stable yields under hotter, drier conditions. Third, higher crop prices (caused by the inelastic demand for agricultural commodities) would make the costs of irrigation feasible for more farmers. Peak demands for irrigation systems are also likely to rise with climate change, indicating the potential need for greater irrigation capacity.

Rising demand for irrigation water could place additional stresses on water systems already being overdrawn, such as the Ogallala Aquifer in the Great Plains. Also at potential risk is the quality of surface and groundwater as depletion of water from these sources increases concentrations of pollutants.

These studies did not consider changes in competing demands for water, which may be altered in a warmer climate. Costs of developing irrigation systems in new locations and increasing capacity in currently irrigated areas may be high, and actual implementation of expanded irrigation systems depends on the economics of each local situation.

4. The extent to which the direct effects of CO_2 may be beneficial is uncertain. Regional changes in U.S. agriculture are predicted even when beneficial physiological effects of increased carbon dioxide on crop growth are taken into account. While the beneficial effects of CO_2 may mitigate or actually overcome negative climate effects on yields in some areas, agricultural productivity shifts occur in any case. Thus, an optimistic estimation of yield increases caused by higher levels of CO_2 does not preclude significant changes in regional agriculture in the future. This result is illustrated in Fig. 1 where changes in regional agricultural acreage are simulated both with and without the physiological effects of CO_2 on crop yields.

Furthermore, few experimental studies have examined the interactive effects of CO_2, water, nutrients, light, and temperature on crop growth and development. Interactive studies are needed to accurately predict the combined effects of all these future stresses on crop yields. Thus, uncertainty exists concerning the extent to which the beneficial effects of increasing CO_2 will be seen in crops growing in variable, windy, and pest-infected (weeds, insects, and diseases) fields under climate change conditions.

The results of the EPA studies indicate a need for continued analyses and research. As mentioned earlier, a strong research effort must be maintained in order to ensure technological improvements in agriculture and limit vulnerability to climate change, including continued development of crops which are drought and heat tolerant, and species acclimated to the projected changed climate regimes. Additional analyses of the impacts of climate change scenarios on major crops will be important, as well as study of the potential effects on specialty crops and other agricultural sectors such as the dairy industry. One of the most crucial areas for further research is the projection of potential climate change effects at the international level, and the implications of the

projected shifts in global agriculture for U.S. trade. Therefore, a study of international effects of climate change should be undertaken. These efforts must be accompanied by continued improvement in our ability to estimate regional climate changes.

It is also appropriate to examine current agricultural policies, such as the U.S. commodity programs, in light of the need for flexibility in adjusting to potential future warming. Do these and other farm policies encourage farmers to adapt as easily as possible to changing climatic conditions? Of course, given the large uncertainties about climate change, policies designed to help U.S. agriculture prepare should also make sense for today. For example, drought planning could be improved, thereby helping today's farmers and also providing insurance against potential future droughts. Other policies to examine in the light of climate change are land-use and water-resource management and water quality regulations. Finally, the implications of potential long-term changes in the levels of U.S. crop exports for the U.S. balance of trade should be considered by relevant policymakers.

While many critical uncertainties remain about the magnitude and timing of impacts, it appears that climate change is likely to affect agriculture and rural communities in the United States significantly in the coming century. If the higher temperatures that are predicted by global climate models occur, changes in regional crop yields, crop irrigation requirements, heat stress on livestock, and infestation of agricultural pests and diseases, may ensue. Farmers can make some adjustments to less severe climate change by planting earlier, substituting better-adapted crop varieties and species, and increasing demand for water for irrigation. More severe climate change will likely require major adaptations, including expansion of irrigation infrastructure, farm abandonment and rural dislocation, in some regions.

The initial analysis of climate change impacts on U.S. agriculture provided by the EPA studies indicates that comparative advantage among farming enterprises and regions and hence patterns of agriculture are likely to shift within the United States. While, on a national scale, the domestic supply of agricultural commodities should be sufficient, concern for our major resources (especially land and water), rural communities, and the environment appears justified. Furthermore, the need to consider climate change effects in a global context, particularly in relation to the role of the United States as a reliable supplier of agricultural export commodities, becomes a necessity.

Agriculture Projects for EPA Report to Congress on
The Potential Effects of Global Climate Change on the United States

Regional Studies

- Effects of Projected CO_2-Induced Climatic Changes on Irrigation Water Requirements in the Great Plains States - Allen and Gichuki, Utah State University

- Climate Change Impacts upon Agriculture and Resources: A Case Study of California - Dudek, Environmental Defense Fund

- Farm-Level Adjustments by Illinois Corn Producers to Climatic Change - Easterling, Resources For the Future

- Impacts of Climatic Change on the Fate of Agricultural Chemists Across the USA Great Plains and Central Prairie - Johnson, Cooter, and Sladewski, University of Oklahoma

- Impact of Climate Change on Crop Yield in the Southeastern USA: A Simulation Study - Peart, Jones, Curry, Allen, and Boote, University of Florida

- Effects of Global Climate Change on Agriculture: Great Lakes Region - Ritchie, Baer, and Chou, Michigan State University

- Potential Effects of Climate Change on Agricultural Production in the Great Plains: A Simulation Study - Rosenzweig, Columbia University

National Studies

- The Economic Effects of Climate Change on U.S. Agriculture: A Preliminary Assessment - Adams, Glyer, and McCarl, Oregon State University

- Analysis of Climate Variability in General Circulation Models - Mearns, Schneider, Thompson, and McDaniel, National Center for Atmospheric Research

- Direct Effects of Increasing CO^2 on Plants and Their Interactions with Indirect (Climatic) Effects - Rose

- Potential Effects of Climatic Change on Plant-Pest Interactions - Stinner, Rodenhouse, Taylor, Hammond, Purrington, McCartney, and Barrett, Ohio Agricultural Research and Development Center

- Agricultural Policies for Climate Changes Induced by Greenhouse Gases - Schuh, University of Minnesota

- Changing Animal Disease Patterns Induced by the Greenhouse Effect - Stem, Mertz, Stryker, and Huppi, Tufts University

- Effect of Climatic Warming on Populations of the Horn Fly - Schmidtmann and Miller, USDA Agricultural Research Service

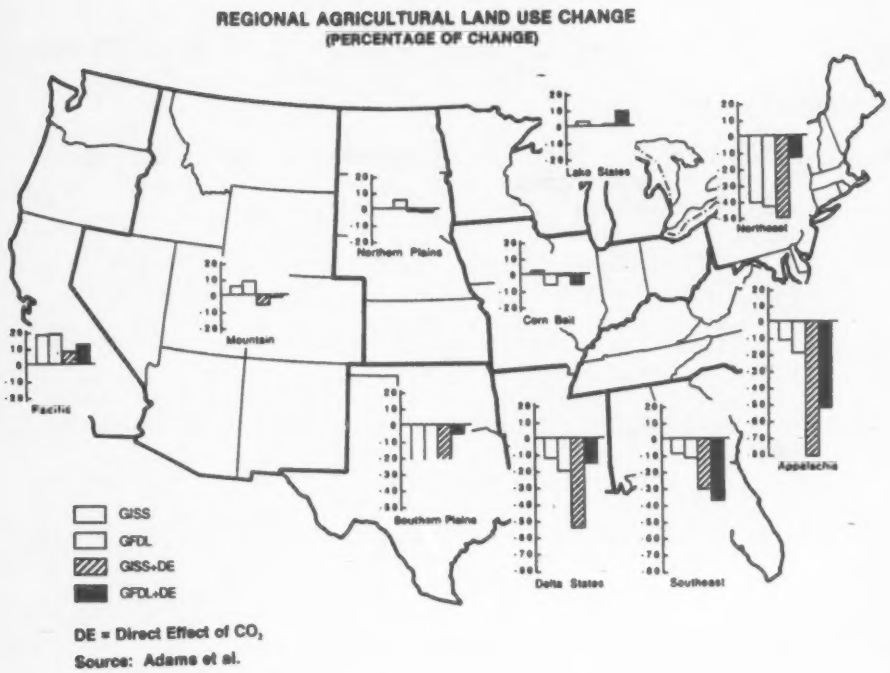

Figure 1. Percent change in regional agricultural acreage simulated by an economic model of the U.S. agricultural sector for the GISS and GFDL climate change scenarios with and without the direct effects of CO_2 on crop yields.

Source: Adams et al.

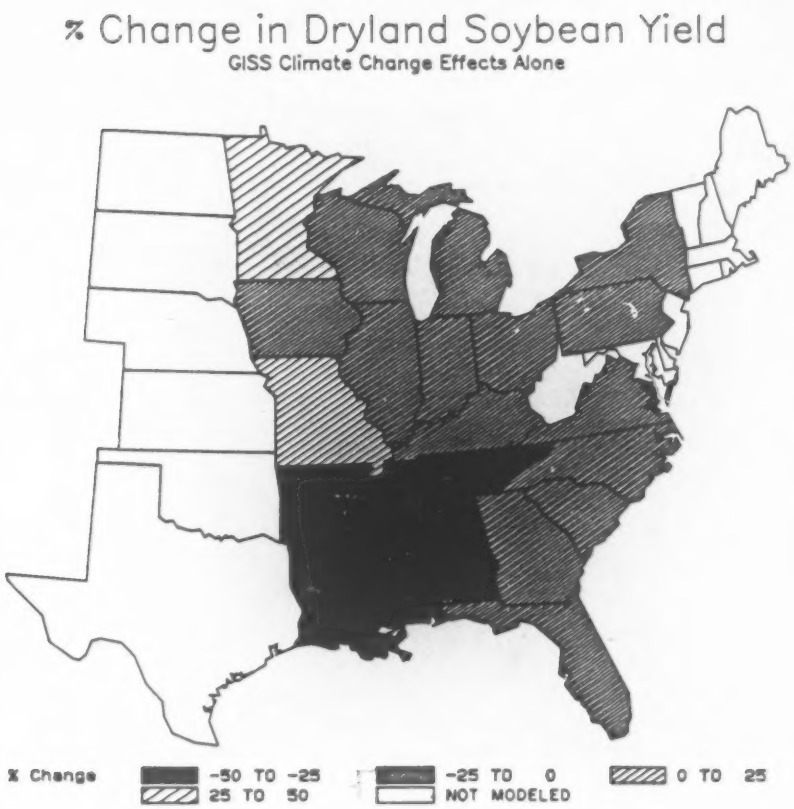

Figure 2. Perecent change in rainfed soybean yields simulated by the SOYGRO model with the GISS climate change scenario.

Source: Peart et al. and Ritchie et al.

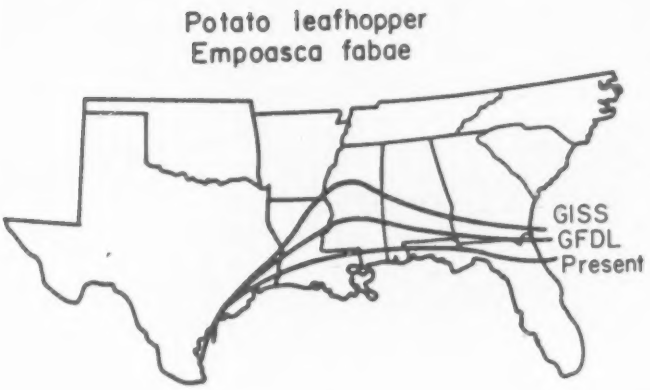

Figure 3. Present and potential (GISS and GFDL climate change scenarios) overwintering range of the potato leafhopper, Empoasca fabae, a major pest of soybeans.

Source: Stinner et al.

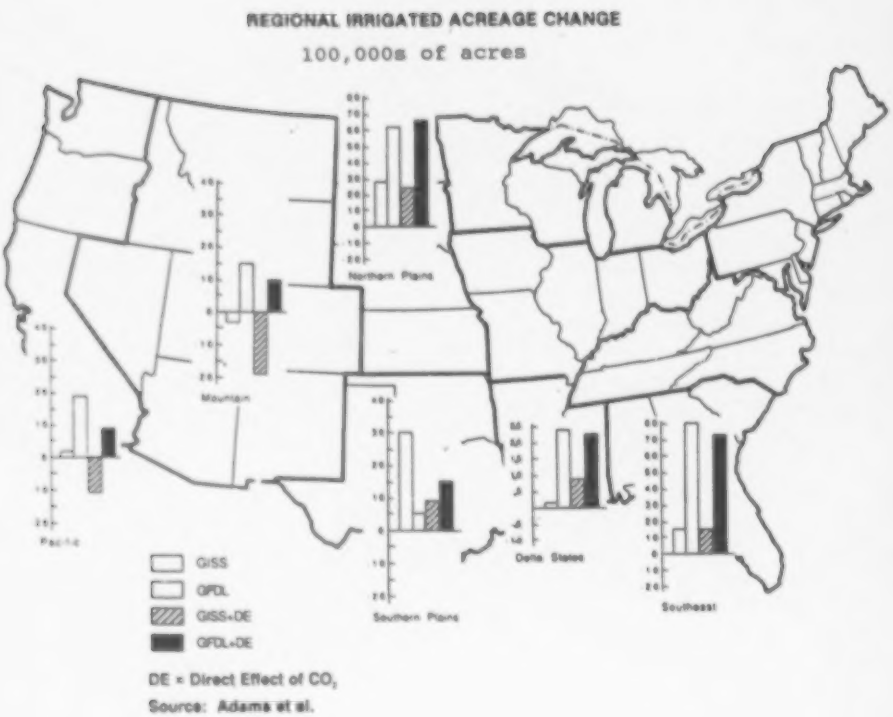

Figure 4. Change (100,000s of acres) in regional irrigation acreage simulated by an economic model of the U.S. agricultural sector for the GISS and GFDL climate change scenarios with and without the direct effects of CO_2 on crop yields.

Source: Adams et al.

Senator BOSCHWITZ. Go ahead, Dr. Moomaw.

STATEMENT OF WILLIAM R. MOOMAW, DIRECTOR, CLIMATE, ENERGY AND POLLUTION PROGRAM, WORLD RESOURCES INSTITUTE, WASHINGTON, DC

Dr. MOOMAW. Thank you, Senator Bond, Senator Boschwitz. It is a pleasure to have the opportunity to testify before the Agriculture Committee today. I would like to focus my remarks primarily on the impacts of global change on forestry and what actions in the forestry sector we could take which might help to offset or mitigate carbon dioxide buildup and, hence, to prevent global warming.

I might just say at the outset that the analysis that we have done at the World Resources Institute suggests that we could utilize expanded forestry opportunities within the United States that would be capable of absorbing carbon dioxide to the extent of about 15 percent of the annual carbon dioxide emissions; and that international programs, which would involve tropical forests, could offset substantially more than that.

Let me just begin by summarizing a few things about the global carbon cycle because I think that is crucial to an understanding of how forestry might play a role.

We may have to move this screen forward just a little bit.

The basic point here is this simply illustrates the various pockets, if you like, in the environment where carbon is found, and the amounts are in billions of tons. And you see that in the atmosphere there is about—the major players here are the atmosphere, which has about 750 billion tons; the surface oceans, which have about 725 billion tons of carbon—that is, about the same amount as the atmosphere; and then there is slightly less in the terrestrial ecosystem, which adds up to about 560 billions tons. Those are the major interactive players.

Now, down here marked "large fossil fuels" is something of the order of 7,000 billion tons, roughly 10 times as much as in the atmosphere, and we are releasing 5.6 billion tons a year to the atmosphere. That is where the carbon dioxide is coming from in one place, and the other place is from deforestation, which is releasing something in the range of about 1 billion tons per year. That is a somewhat rough estimate, but it is roughly of that order.

The major point in terms of using forestry to offset the emissions of fossil fuels is that the forests could begin to take up some of the carbon dioxide in photosynthesis, and I will be talking about a couple of specific proposals for that in just a moment.

The other area which I would like to just mention in passing is that you can see that, in soils, there is an amount of the order of 1,400 billion tons, which is twice as much carbon as in the atmosphere, and the loss of soil carbon in agriculture and forestry may be contributing to global warming and also provides us with an opportunity for storing carbon if we do our forestry and agricultural policies appropriately.

Let me just state briefly some things about what might happen to forests if we had significant warming. If I could have the next transparency, this is the so-called Holdridge Classification Scheme which shows the original distribution in North America of various

kinds of plant communities. You can see that in the Upper Northeast there is the mixed deciduous forest, I believe in blue; and above it the Canadian taiga forest and below it the Southeastern Forest. Were we to double the amount of carbon dioxide in the atmosphere based strictly on projected temperature changes alone, the next graphic simply shows the change that would take place in where these various forests would grow.

What we see happening is that the Northeast Forest is now moved into Canada to a large extent. The Canadian Forest is gone from the continent, which is the source of a lot of our spruce forests that is used in North America. The Southern Forest moves north. Right here in the southeast part of Georgia, which is an important source of commercial forests, is now not capable of sustaining those forests. And we see a major movement of that yellow area from the Midwest up into Canada.

Senator BOSCHWITZ. What is the yellow area?

Dr. MOOMAW. The yellow area is essentially where the Great Plains are, and so not a forestry issue but really more an agricultural issue. Not that I think that is unimportant; it is just that that has already been covered.

Let me just show you on the next slide. There have been some remarkable studies based upon the ancient pollen data that was referred to earlier, which suggests something about the way in which forests can move. Let me just say that when we talk about forests migrating, one has the image of a Larson "Far Side" cartoon of the lady looking out the window and saying, "Look, George, here comes the forest." And that is not the way it works.

In fact, the way it works is that individual species have more tolerance for warmer weather, and those will be the ones that survive. And the others will gradually disappear.

We know from some remarkable work done by Dr. Margaret Davis at the University of Minnesota that the rate at which different species migrated northward after the last glaciation, which is shown on this particular slide here, was quite variable. So that the composition of, let us say, the great northeast midwestern forest changed rather dramatically over time, and it was not until about 500 years before the first European settlement that it achieved the kind of mix and composition that we think of as the forest primeval. Trees like chestnuts migrated much more slowly than did oaks or beeches or other species.

We are now moving into a climate regime in which many of these species will be supplanted by species like aspen and birch, which have much less commercial value and which grow and reproduce much more rapidly.

May I have the next transparency, please?

There are some projections, again, based on the work done for the EPA study, and the lower panels represent sugar maple and the upper panels hemlock. The left-hand panel represents the current range of sugar maple and hemlock, which, as you can see, extends actually, I guess, on the west from Senate Bond's State to Senator Boschwitz's State, and on the east up to Senator Leahy's State. And what we can see as we move across, Panels B and C simply represent projections of the future range 100 years from now using two different climate models.

You can see, for example, that for sugar maple that range becomes severely restricted in both cases, moving quite a bit northward. I would not necessarily take those boundaries literally, but I think the general trend of both of those projections is reasonable and what is to be expected.

If I could have the final transparency.

The basic idea I want to put forward is that we can expect some significant problems for our forests if there is climate change; and, secondly, that there will be associated economic problems as well. Now, I would like to suggest a way of addressing this, which is to look at what forestry might do to offset some of this buildup. In order to do that, we need to look a little bit for a moment at the different economic sectors that are producing carbon dioxide, because I would like to tie some of these policies to what is happening in the economic sector.

This is some data that was put together by Dr. James MacKenzie at the World Resources Institute based on Department of Energy data. What it shows is that of the four traditional sectors of energy use, since 1973 two of them have decreased in their output of carbon dioxide by a little bit; namely, the commercial/domestic sector, and the industrial sector. They have both become more efficient over time, use fossil fuels more efficiently, and produce less carbon dioxide than they did a decade-and-a-half ago.

However, electric power generation and transportation have been increasing in carbon dioxide output. Now, those sectors have been getting somewhat more efficient, particularly the transportation sector. But that is leveling out now, and we are using more cars and we are putting more carbon dioxide into the atmosphere.

So what I would like to suggest is that we might think about tying a policy of reforestation to the emissions coming out of these particular sectors. The World Resources Institute has actually carried out, has brokered, really, an arrangement between a power company, AES, located here in northern Virginia, building a coal-burning power station in Connecticut with a tree-planting project in Central America that will offset all of the carbon dioxide emissions from that plant over its 40-year lifetime. One could envision doing that in the United States, as well as doing the offsets internationally. The tying of those two things together I think is an intriguing idea. It will not solve the whole greenhouse problem, but it is a very useful concept, I think, for thinking about how we might want to proceed.

Let me say something specifically about encouraging carbon storage on Federal lands, in particular in national forests. I think that increasing growth rates on national forest lands is something that would be useful, particularly in those areas which are timberlands, which are used for the production of timber. I would like to suggest that this can be done through more intensive management. Also, we could accelerate reforestation activities which is chronically always a little bit behind. It has always been a problem, and it is not entirely the Forest Service's fault. There is the issue of the funding needed to address that problem.

Second, let me propose that we consider adding carbon storage in national forests as one of the multiple uses of national forests. When we manage our national forests, we do so under the provi-

sions of the Multiple Use Sustained Yield Act, as it has been modified over the years, particularly in 1976 by the National Forest Management Act. And I would like to suggest that this committee consider the possibility of adding carbon storage as one of the multiple use goals of national forests.

We might, with accelerated management, with growth practices and thinking of carbon sinks in national forests, be able to offset something on the order of 2 percent, of the carbon dioxide emissions of the United States. There are also other public lands on which there could be additional planting. We are talking about closing down some military bases, or perhaps planting trees on active military bases. There are BLM lands which may be suitable. There are other public lands at the State and local level.

Another concern that I have with the U.S. national forests is that, according to a study done by Robert Repetto at the World Resources Institute, we are currently subsidizing timber sales in national forests to the tune of about $85 million a year. It seems to me to make little sense to continue those subsidies. It does not make sense to me economically. It also does not make sense to me if we are going to try to use those forest lands for carbon storage purposes.

At a public awareness level, it is very difficult to tell the Brazilians to stop subsidized cutting and destroying of the Amazon, at the same time which we are, in fact, subsidizing the cutting of some of our forests in the United States. So, just internationally, we have a bit of a problem there.

There are other proposals on other lands; for example, the CRP lands, the agricultural lands that are being set aside. Dr. Dan Dudak has proposed planting trees there to offset carbon emissions. I think that is a very good idea. We can also promote more rapid growth on private lands, which the Forest Service can encourage through its private land owner services and so forth.

Senator BOSCHWITZ. Dr. Moomaw, can I ask you to also summarize?

Dr. MOOMAW. Yes. I am right at the end.

We might also investigate the possibility of increasing the use of biofuels from forest products. And if we add up all these possibilities, along with improved soil conservation matters and possibly some urban forestry, we might get up to this figure of about 15 percent, offsetting 15 percent of the carbon dioxide emissions of the United States throughout the period when we make a transition over the next century or so to non-fossil-based fuels. There is even a larger potential, I think, in the international area because tropical forests are easily 10 or 15 times the size of U.S. forest in their capability for storing carbon.

Thank you.

[The prepared statement and attachments of Dr. Moomaw follow:]

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TESTIMONY OF WILLIAM R. MOOMAW
BEFORE THE SENATE AGRICULTURE COMMITTEE
DECEMBER 1, 1988

Mr. Chairman, I am William R. Moomaw, Director of the Climate, Energy and Pollution Program of the World Resources Institute (WRI). I appreciate the opportunity to appear before you today on the subject of forestry policy and global warming.

As you are aware, the public concern over global warming has surged recently, partially in response to the heat and drought of this past summer. Scientific debate on the likelihood and magnitude of human-induced global warming, however, has been underway for almost a century. Notwithstanding remaining uncertainties about the timing and severity of global warming, it is now generally accepted within the scientific community that fossil fuel combustion, as well as other industrial and agricultural activities of human societies, have already committed the planet to significant warming, and that additional warming in likely far into the next century and beyond.

The basic mechanism for global warming was first proposed in 1827 by the French mathematician and physicist Jean Fourier. He suggested that the earth is as warm as it is because the atmosphere has special greenhouse-like properties. These properties permit solar energy to enter and strike the earth, but then absorb a portion of that energy as it attempts to radiate back into space. This trapped energy keeps the planet warmer than it would be in the absence of the atmosphere. In 1896, the great Swedish chemist Svente Arrhenius not only demonstrated that it was the traces of water vapor and carbon dioxide in the atmosphere that trapped the infrared energy, but also calculated the amount of additional warming that could be expected if the combustion of fossil fuels doubled the atmospheric carbon dioxide concentrations. His estimate of a 10 degrees F warming is not much higher than the 3 to 8 degrees F increase that current models project for a doubling of atmospheric CO_2.

The pace and eventual magnitude of global warming depend on variables as disparate as global population growth, energy supply mix, changes in ocean currents, deforestation rates, chlorofluorocarbon (CFC) consumption, and positive and negative climatic feedbacks. One potential feedback is the effect of global warming on clouds. Because of the complexity of the feedback mechanism, however, we remain unsure as to the magnitude, type, and distribution of any increase in cloudiness, and can therefore not be sure whether increased cloudiness would cool or further warm the planet. Other feedbacks are more straightforward, such as the likelihood that global warming will increase the rate of decay of organic matter, potentially adding significantly to the release of CO_2 and methane into the atmosphere.

Our current understanding of the interplay between atmospheric concentrations of greenhouse gases and global temperatures suggests that under a "high emissions"

scenario we could commit ourselves to a 3 to 8 degrees F rise in average global temperatures by as early as 2015, and even under a "base case" scenario such a commitment is projected to occur by 2030. Indeed, current data suggests that the planet has already warmed by 1 degrees F during the past century, consistent with projections of the impacts of past additions of greenhouse gasses to the atmosphere, and that we may already be committed to an additional average temperature rise of 2 to 4 degrees F.

Human activities in a wide variety of areas are contributing to changing the planet's atmosphere and overall heat balance. Any significant temperature changes which result will have profound consequences for all sectors of human activity. Attempting to slow or adapt to global warming thus suggests a complex mosaic of anticipatory and adaptive policy strategies. Today, I would like to address just one part of the global warming puzzle, namely forestry and forestry policy. Forests are very vulnerable to the impacts of global warming, and the timespans required for forest regeneration suggest that the consequences of global warming will take a long time to reverse, if that is even possible. A variety of specific approaches can be envisioned which could help protect forests from some of the impacts of global warming, and which could use forests to reduce or mitigate the effects of domestic and international CO_2 emissions, thereby slowing global warming. Overall, domestic forestry initiatives may well have the ability to offset or reduce U.S. CO_2 emissions by more than 15 percent, equivalent to the annual emission of more than 200 million tons of carbon. Internationally, much more could be accomplished.

My testimony will include a review of the possible implications of global warming for the health, distribution, and productivity of our forests, suggestions for the types of adaptive strategies we would be well served to consider as part of our ongoing forest management activities, and thoughts about the specific role forests and forestry policy can play in moderating the pace and severity of global warming.

FORESTS IN THE GLOBAL CARBON CYCLE

In considering the general role of forests in affecting or responding to climatic change, it is helpful to review their role in the global carbon cycle. The carbon cycle is important because it determines how much carbon, in the form of carbon dioxide (CO_2), is in the atmosphere at any one time. It is perturbations to the carbon cycle, primarily the annual release of six billion tons of carbon through the combustion of fossil fuels, as well as the annual release of over a billion tons of carbon through deforestation, that are expected to be responsible for 50 percent of the global warming seen in the next several decades. As a result of these perturbations, the concentration of CO_2 in the atmosphere has increased from a preindustrial level of about 280 parts per million (ppm) to today's levels of 350 ppm.

Figure 1 illustrates the global carbon cycle. The atmosphere now contains some 750 billion tons of carbon, which is already 150 billion tons more than it contained prior to the commencement of large-scale fossil fuel combustion. The surface ocean and biota contain some 725 billion tons, while terrestrial life accounts for some 560 billion tons. Another 1,460 billion tons is sequestered in ground litter and soils. The vast majority of global carbon is sequestered in the deep ocean (some 38,000 billion tons) and in fossil fuels (up to 7,000 billion tons). It is believed that the deep ocean carbon is stable over long periods of time. Similarly, fossil fuels would be a stable

carbon reservoir in the absence of human intervention. Human activities, however, open a conduit for carbon sequestered in fossil fuels and terrestrial tropical forests to escape to the atmosphere.

The injection into the carbon cycle of large quantities of carbon from fossil fuel combustion, or the reallocation of large quantities of carbon between terrestrial biota and the atmosphere through the deforestation of 25 million acres per year, raises the size of the atmospheric reservoir of carbon in the form of CO_2. This in turn contributes to global warming. There are two basic ways that forestry policies can help to slow global warming. The first is to slow and eventually reverse net deforestation, now a particular problem in the tropics, which allows the leakage of sequestered carbon into the atmosphere. This approach can be augmented by increasing the net size of the terrestrial carbon sink by expanding the standing crop of trees, as well as by building up the carbon content of forest, grassland, and agricultural soils. Secondly, forestry productivity rates can be increased so that forests absorb a higher percentage of the annual carbon dioxide emissions from human activities.

IMPACTS OF GLOBAL WARMING ON U.S. FORESTS

While average global temperatures may rise by between 3 and 8 degrees F during the next century, temperature increases will be proportionately greater at northern latitudes. There is no doubt that the expected degree of warming would have dramatic impacts on forests around the world.

First, as shown in Figures 2 and 3 by changes in lifezone distributions, the ranges of most forest species would move up in elevation and north in latitude. Because a 1 degree F temperature change is roughly equivalent to a latitudinal shift of 40 miles, and because particularly dramatic temperature changes will occur in high latitudes, species ranges could shift by 200 to 500 miles. Although all species of fauna and flora are constantly shifting their ranges in response to slowly changing climate, as shown in Figure 4, the severity and speed of likely future climatic changes will be an order of magnitude beyond those experienced by species in the past. This will pose severe problems for species adaptation. Tree species will be unable to extend their geographic range nearly as quickly as climatic and other environmental conditions would dictate, or to adapt readily to the specific soil and hydrological circumstances found there. There will therefore be a substantial time lag in the colonization of new areas by forests. In attempting to migrate northward, species will be severely constrained by barriers not faced in previous migrations, e.g. metropolitan and agricultural development. Many species of plants and animals will no doubt become extinct.

Second, to whatever extent tree species successfully track changing climatic ranges, the species composition of the forest communities we are now familiar with will be quite disrupted. It will be individual species rather than forest communities that adapt and migrate as best they can. Major changes will occur to ecosystems, and the relative composition of economically valuable vs. less valuable tree species is likely to change considerably. Figure 5, taken from the new EPA effects report, shows the projected shift in range for sugar maple and hemlock which would be projected to accompany a 3 to 8 degrees F temperature increase.

Third, changing species ranges will not neatly accommodate current patterns of resource ownership. Those plant and animal communities around which our national forests, national parks, and wildlife refuges are built will suddenly be forced to move north. Will we attempt to establish a whole new set of mobile species refuges and national forests to track their migration? And if global warming is proceeding rapidly, would such a strategy make sense even if it were physically possible? In the absence of such efforts, what will prevent the extinction of many of these species?

Fourth, already established forests in the southern parts of species' current ranges will be severely stressed as the climatic conditions favorable to their continued growth and regeneration move northward. There is some argument that higher atmospheric concentrations of CO_2 will have a fertilizing effect on forests, and that this may offset some of the difficulties imposed by global warming. For many forests, however, nutrient and water availability, rather than CO_2 concentrations, are likely to be the variables currently limiting forest growth. These variables, along with new ones such as possible increases in cloud cover, would offset much if not all of the CO_2 fertilization effect. In addition, water availability and soil moisture will change, fire regimes will become more intense, and seedlings may be unable to regenerate. Insect pests and other pathogens undertaking more rapid migrations of their own from points south will add to the problems of these forests. These stresses are likely to be reflected in reduced general forest health, altered growth rates, lower quality of lumber, and deteriorating wildlife habitats.

ADAPTING FOREST MANAGEMENT STRATEGIES TO GLOBAL WARMING

As just discussed, any significant amount of global warming will badly stress existing forests, and do serious damage to spatially defined structures such as the National Forest system. The best strategy we can pursue to protect our forests and the timber industry that is dependent on them is to slow as much as possible the rate of global warming, thereby giving natural adaptation more time to work. Ultimately, we must strive to halt human-induced global warming altogether. Nevertheless, and even if one accepts that significant consequences will accompany global warming, it could be argued that over the long term we will adjust to whatever changes in forest distribution and composition occur. But given the ecological and economic importance of forests both domestically and internationally, this is a high-risk approach. Instead, we should undertake to protect our forests as best we can from the impacts of global warming. In addition, the prognosis for U.S. forests may be improved by helping them to adapt to an unparalleled rate of climate change.

First, we should act to minimize other human-imposed stresses on the forests. The World Resources Institute recently published a study of the impacts of air pollution on agricultural and forest production. In Ill Winds: Airborne Pollution's Toll on Trees and Crops, WRI researchers conclude that ozone, acid rain, and other pollutants are having significant effects on the growth rates and health of standing forests in the Northeast. In what may well be a related issue, the Forest Service is attempting to determine the causes of rising mortality and decreased growth on commercial timberlands in the southeastern U.S. The fact is that pollutants emitted by the combustion of fossil fuels for electricity production and transportation are seriously stressing domestic forests. The results of this stress will become increasingly evident as global warming adds to the strains facing forests, and as their abilities to grow and adapt to changing conditions decrease as a result.

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Beyond trying to control air pollution, forestry policy should address all sources of stress to standing forests. Current harvesting and management practices should be reevaluated in light of global warming to determine whether they unnecessarily stress the forests being managed. The implications of global warming for drought, fire ecology, pest infestation, and future species mix also need to be considered during such a reevaluation.

Second, we should be undertaking considerably more research to determine how to help forests adapt to changing climatic conditions. This includes not only research into how to artificially accelerate a species' ability to migrate with changing climatic conditions, but how existing forest growth and stability can be encouraged in the face of changing environmental conditions. For example, should routine replanting of harvested areas take the place of increasingly uncertain natural regeneration? Should new species be emphasized during replanting programs, species that are better adapted to the conditions which may prevail 50 years from now in a particular area? These are just some of the questions foresters are beginning to raise as they consider the implications of global warming.

USING FORESTRY POLICY TO SLOW OR MITIGATE GLOBAL WARMING

Trees are approximately 50 percent carbon by dry weight. As stated previously, deforestation and the subsequent release of carbon to the atmosphere can aggravate global warming. Conversely, adding significantly to the standing stock of trees can remove large quantities of CO_2 from the air, thus helping to slow and mitigate the buildup of atmospheric CO_2.

More and more attention is now being given to the prospects for fighting global warming through aggressively increasing the amount of carbon stored in world forests. Unfortunately, the destructive impacts global warming is likely to have on domestic and world forests makes using forests to combat the rate or severity of global warming a somewhat tenuous proposition. It may be more than we can accomplish to maintain a forest system similar to the status quo in terms of carbon sequestration. Nevertheless, the potential usefulness of forests in combatting global warming is a policy option that we can begin to implement now, and one that is certain to slow the growth of the major greenhouse gas, carbon dioxide.

Forestry as a Part of the Solution

Several estimates exist with respect to how many acres of trees would have to be planted to solve, albeit only temporarily, the problem of global warming by absorbing in new biomass enough carbon dioxide to offset the emissions of fossil fuel combustion. These estimates range from 1.2 billion acres to 3 billion acres, compared to a total U.S. surface area of some 2.2 billion acres. While it is conceivable that in the throes of a global crisis induced by global warming such an ambitious program might be undertaken, this approach cannot be expected to "solve" global warming anytime soon, and we should not rely on it.

Nevertheless, it does appear that forestry can play a significant role in absorbing a significant portion of total CO_2 emissions. As Figure 6 clearly shows, the electric utility and transportation sectors of the U.S. have increased their CO_2 emissions since 1973, whereas the industrial, commercial, and residential sectors have

example, the North American Electric Reliability Council estimated in 1987 that over 25,000 megawatts (MW) of electric power generating capacity will be added in the U.S. through 1996, emitting over 45 million tons of carbon annually. We estimate that to absorb this amount of carbon would probably require the planting of approximately 30 million acres of trees in the U.S., a surface area equivalent to the state of Mississippi. Perhaps the builders of new facilities such as powerplants should be required to offset a new project's CO_2 emissions, just as they already have to do under some circumstances for a variety of other air pollutants. The concept of offsets might also be taken beyond stationary sources to include incremental additions to U.S. automobile and truck fleets, the CO_2 emissions of which are likely to grow by some ten million tons annually (2.7 million tons carbon). To absorb the additions from the transportation fleet would require the planting of one to two million acres of new forest every year. While superficially a modest step towards addressing global warming, even offsetting incremental additions to current levels of CO_2 emissions from the power generation and transportation sectors could play a significant role in slowing global warming.

It must be accepted from the outset, however, that the ultimate contribution of forestry can only be to facilitate a transition from our reliance on fossil fuels to non-CO_2 releasing fuel sources over the next 50 to 75 years. There is no conceivable way that forestry could indefinitely compensate for the quantities of carbon that would be emitted to the atmosphere through an indefinite reliance on fossil fuels. Even if some enormous surface area of land could be planted in coming years, the withdrawal of large quantities of CO_2 from the air would continue only as long as the trees were rapidly growing.

In addition, the relatively small part that U.S. forests play in the global carbon cycle suggests that fully effective forest-based mitigation strategies will have to be international in scope. U.S. National Forests appear to be a repository for some 3 billion tons of carbon. This compares to some 12 billion tons for all U.S. timberlands, and less than 20 billion tons for U.S. forests as a whole.[1] This compares to estimates of the carbon content of tropical forests of from 200 to 500 billion tons.

Policies to Encourage Carbon Storage on Federal Lands

The actual magnitude of the role domestic and global forestry can play in offsetting some proportion of CO_2 emissions is still uncertain. It is obvious, however, that forest policy can certainly affect the volume of carbon sequestered in standing stock, as well as the growth rates of the nation's forests. Some aspects of forest management practices domestically and around the world require a fundamental rethinking in light of the threats posed by global warming. At the domestic level, the following types of measures would contribute to maximizing the role of our forests in combatting global warming:

- Increasing tree growth rates on national forest lands managed for timber should be encouraged through more aggressive management and by accelerating the

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[1] Forest is classified as timberland only when it is capable of producing at least 20 cubic feet per acre of industrial wood annually, and when it has not been reserved from timber harvest. Only two-thirds of the nation's forests are classified as timberlands.

- Increasing tree growth rates on national forest lands managed for timber should be encouraged through more aggressive management and by accelerating the replanting of harvested areas. Waiting for natural regeneration can postpone significant carbon reaccumulation by several years, and it can facilitate the release of soil carbon. While there has been reported progress in reforesting a long-standing backlog of U.S. Forest Service harvested areas, much of this progress may be illusory. A 1985 report to the Committee on Appropriations by its Surveys and Investigations Staff revealed that the Forest Service sometimes claims treatment of backlog acres even when no tree planting is planned, before planned planting has occurred, or when only a part of an area is in fact treated. The report concluded that large portions of the backlog acres were removed from the rolls not by reforestation, but by administrative fiat reclassifying the land out of the timberland system. A more recent report by the Congressional Research Service comes to the same conclusion. Yet if the land was not appropriate for reforestation, why was it cut in the first place? Such land may best be utilized as a carbon sink rather than being cut at all. I believe the Forest Service needs additional funding to actually keep up with the reforestation needs of harvested timberlands. I would encourage the Committee to authorize the additional funds needed for reforestation activities by the Forest Service, with an eye toward improving the role of these lands as carbon stores.

- I suggest that carbon fixation and storage to slow the building of atmospheric carbon dioxide be added to the multiple use management criteria for national forests. Taking into account the carbon storage role of these forests would have some significant management implications. In timberlands on the Pacific Coast, average standing carbon stock is some 42 tons per acre, yet average growth is only about 1 ton per acre. Forests with naturally low growth rates, such as Tongass National Forest, are even more disparate in standing stock vs. annual growth, and may best serve carbon storage purposes by being left standing as carbon reservoirs. It would be very difficult to make up through new growth the large amount of carbon released from the trees and the soil during the harvesting of such a forest. Conversely, the productivity of other timberlands should be maximized through rapid rotations to increase the rate of new carbon fixation, particularly if the forest's products serve to advance long-term carbon storage goals, e.g. through the production of construction materials. It will require considerable site-specific research to determine how particular forest stands should be managed in the most appropriate way to meet a stated policy goal of carbon fixation and storage.

- The potential for reforestation or afforestation on other public lands should be evaluated, and planting programs undertaken where appropriate. These lands might include active and closed military bases, Bureau of Land Management lands, Indian reservation lands, as well as state and local parks and forests. Although it is very difficult to determine how much potential for afforestation exists on these lands, it must amount to several tens of millions of acres.

- Most of the steps suggested above will require research into how best to balance the sometimes competing management criteria of timber production, carbon fixation, habitat development, and recreational access. Beyond this research, improvements continue to be needed in the Forest Service's data base of our national forest resources. The Service needs funds to improve its

information gathering and analysis capabilities with respect to forest growth and regeneration status.

- Additional research and development is required to develop faster growing trees that can adapt to changing environmental conditions. Unfortunately, expenditures for Forest Service research and development fell by 25 percent in real terms between 1977 and 1986, and have only marginally recovered since then. I urge that the research budget be returned to at least its former level, and preferably increased.

- Subsidies which encourage the uneconomic cutting of forests should be ended. Cutting down trees when it makes no economic sense is even less prudent when done in the face of global warming. The evidence suggests that heavily subsidized, below-cost timber sales in the Tongass National forest and many other national forests cost U.S. taxpayers more than $85 million dollars per year, despite the fact that at least some of the areas are simply unsuitable for timber production and should be managed for other purposes. According to the Congressional Research Service, more than 95 percent of the timber sale receipts on 8 national forests in 1987 were accounted for by deposits to the Knutson-Vandenberg (K-V) accounts to cover replanting, and by credits for road-building. K-V deposits and road credits exceeded 75 percent of the timber sale receipts in 35 national forests during the same year. Despite Congressional attempts to reduce indirect subsidies such as road building, they continue to be a major factor in promoting uneconomic harvesting activity. If the total costs of administering timber sales were to be included, many of these timber sales are properly classified as net losses to the U.S. taxpayer. In light of the valuable role of standing forests for carbon storage, counterproductive policies such as those cited by the Congressional Research Service, and discussed extensively in earlier governmental and non-governmental studies, should be discouraged. Aside from the economic issue, it is very difficult for the U.S. to argue that countries such as Brazil should be ending the subsidies which are contributing to the deforestation of the Amazon rain forest when we continue to subsidize the uneconomic harvesting of our own forests.

The problem of finding funds to support the research and reforestation program costs is a severe one during times of tight budgetary constraints. I would propose that the funding for these new programs come from the savings achieved from the eliminated subsidies, and possibly from revenues collected through a charge on the emissions of carbon dioxide. Alternatively, a specific offset program could be instituted through which a prospective major emitter of CO_2 would be required to fund forestry or other activities which would in effect offset the quantity of carbon expected to be emitted.

Policies to Encourage Carbon Storage on Non-Federal Lands

Because federally owned timberlands are less than 20 percent of total U.S. timberlands, strategies intended to increase carbon fixation through forestry must involve private lands as well. This is particularly the case because it is on private timberlands that the greatest increases in forest productivity are achievable according to the Forest Service. A number of approaches are possible:

- It is already Congressional policy that some proportion of the lands set aside as part of the Conservation Reserve Program (CRP) should be forested. In light of the seriousness of the problem of global warming, perhaps the target for forestation on these lands should be raised considerably from the current 12 percent, and the contract terms of the CRP should be modified so as to provide additional incentives for such forestation. Dr. Daniel Dudek of the Environmental Defense Fund has already detailed a proposal through which the CO_2 emissions of the previously discussed 25,000 MO of powerplants to be constructed by 1996 could be cost-effectively offset. Dudek proposes that 10 million acres of new forests on CRP lands could annually absorb over 45 million tons of carbon, thus offsetting the powerplants' emissions. In addition to forest establishment costs of 1.3 to 1.6 billion dollars, Dudek estimates that the annual costs of the program would amount to 0.33 to 0.67 cents per kilowatt hour (kWh). Our own analysis assumes more modest growth rates for the trees being planted,[2] and suggests that up to 30 million acres of new conventional forest might in fact be required. Because of the significant potential for carbon fixation, however, and because of the ancillary benefits involved in reforesting CRP lands, we see the use of CRP lands for carbon storage as an excellent idea that should be further investigated and encouraged.

- Increasing timber growth on private timberlands needs to be encouraged. Accelerating the regeneration or replanting of harvested lands has significant potential, as does more intensive management. The Forest Service estimates that growth on private non-industry lands could be cost-effectively increased by almost four billion cubic feet per year (about 28 million tons of carbon), an increase of some 30 percent over current growth rates. This increased growth could mitigate over 2 percent of net U.S. carbon emissions, or over 50 percent of the emissions from new powerplants to be built in the coming decade. In encouraging such growth, however, competing interests in the form of the economic value of forest products, biological diversity, and other values must always be considered.

- The potential for forest-derived biofuels should be better assessed, and fostered if found worthwhile. Foresters at the Oak Ridge National Laboratory estimate that in addition to the three percent of total U.S. energy consumption currently provided by wood fuels, production of liquid fuels such as methanol from fast growing tree plantations could on a net basis add another 4 quads to

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[2] Many variables contribute to the growth and consequent carbon fixation rates achieved in forestry projects. In conventional forestry trees are planted and left to grow for an extended period of time, generally without extensive additional inputs. In intensive fast-rotation forestry trees are treated as a 5 to 8 year crop, and are intensively managed to maximize growth potential. The carbon fixation rates achievable under these two extremes no doubt differ dramatically. It is uncertainty over the type of forestry to be employed and the carbon fixation that is achievable that underlies the wide range of estimates of land area requirements. This uncertainty points up the need for additional forestry research and development activities.

U.S. renewable energy resources, thus reducing U.S. fossil fuel consumption and CO_2 production by some 6 percent. One must be careful, however, in assessing the net energy balance of such biofuel projects, and especially the fossil fuel inputs, to insure that there is a real reduction in CO_2 emissions. Some biofuel projects in the past have relied so heavily on fossil fuel inputs in the form of fertilizers and other aids that many of the energy benefits claimed for the resulting biofuels were not met on a net basis.

- Farming and forestry practices which encourage the buildup of large quantities of carbon in the soil should be investigated and encouraged. Globally, two to three times as much carbon is stored in soils as is found in surface biomass. In light of the many depleted soils domestically and around the world, and the rapid rate at which additional soils are being depleted, it is likely that a huge amount of carbon could be sequestered in this manner. Unfortunately, many prevalent agricultural and forestry practices result in the release of carbon from the soil to the atmosphere, rather than its sequestering. Delaying reforestation of harvested forests, for example, facilitates carbon release through wind and water erosion of the soil and subsequent oxidation.

- A variety of "urban forestry" projects are currently underway, and should be encouraged. Dr. Arthur Rosenfeld of the University of California at Berkeley has shown that urban tree planting can help cool down urban areas and significantly reduce air conditioning bills. In a similar vein, the American Forestry Association (AFA) recently kicked off a campaign which it hopes will result in the planting of 100 million trees. Urban forestry could conceivably reduce U.S. energy consumption by 0.6 percent by reducing cooling requirements, thereby lowering carbon emissions by some 10 million tons annually. Interestingly, the direct carbon fixation benefits of planting the trees is very modest. Even complete AFA success with its goal of planting 100 million trees around the country would probably drain less than one million tons of carbon out of the atmosphere each year.

Each of the individual forestry-based approaches discussed above appear quite modest in their ability to offset domestic CO_2 emissions. Overall, however, these programs could reduce or offset domestic CO_2 emissions by more than 15 percent, or more than 200 million tons annually. These programs must be encouraged as a few of the many incremental steps that will be needed to successfully slow the pace of global warming. They are also very valuable as a means through which to raise public awareness around the country.

Policies to Encourage Carbon Storage Internationally

As mentioned previously, tropical forests are much larger carbon sinks than domestic or even temperate forests generally. In addition, they help stabilize global and regional climates, they shelter most of the world's genetic resources, and they represent valuable assets for economic development. Unfortunately, tropical forests are being felled at a rate of some 25 million acres per year, the equivalent of losing 25 percent of the U.S. National Forest system annually. The U.S. should help save tropical forests for many reasons including carbon storage, and there are a number of actions the U.S. should take to contribute importantly to addressing the tropical deforestation crisis:

- The CO_2 emissions of domestic powerplants and other facilities could be mitigated through forestry projects in other countries. Because of the global nature of the carbon cycle, planting trees abroad can be just as effective against global warming caused by U.S. CO_2 emissions as planting trees domestically. This is the principle behind the recently announced initiative by Applied Energy Services (AES), a domestic power company, and World Resources Institute to develop and fund a forestry project in Guatemala. This project is intended to have the effect of offsetting the carbon emissions of a soon to be constructed AES power plant which will emit some 15 million tons of carbon over its 40 year life. The forestry project, administered by the relief agency CARE, is intended to both fix and prevent the release of a total of more than 16 million tons of carbon over the same period. While carbon fixation forestry within the U.S. may be more reliable than foreign projects due to the population and other pressures existing in countries like Guatemala, the costs of such projects are much lower abroad, and they carry with them many ancillary social and economic benefits.

- The U.S. should encourage the full funding and implementation of the Tropical Forestry Action Plan (TFAP), prepared under the joint sponsorship of the U.N. Food and Agriculture Organization, the World Bank, the U.N. Development Program, and World Resources Institute. The TFAP provides a global framework for stimulating action to reduce deforestation and promote the sustainable use of tropical forest resources. National action plans are being developed within the TFAP framework in more than 50 countries, with support and assistance from bilateral and multilateral development assistance agencies. USAID should play a leadership role in this process.

- Steps should be taken to ensure that U.S. development assistance through bilateral and multilateral channels not contribute to the problem of tropical deforestation. The U.S. should push for a swift end to development assistance projects and programs, both bilateral and multilateral, that directly or indirectly promote deforestation. Various development projects in the power generation, water resource management, transport, mining, and commercial agriculture sectors have had serious adverse impacts on tropical forest resources.

- Development assistance programs should emphasize the need for reform of current economic and other policies within developing countries that encourage deforestation, such as subsidies and other fiscal incentives for forest exploitation and development in forested areas. The multilateral lending agencies, particularly the World Bank, have begun to address broader policy issues affecting the forest sector in the formulation of policy-based forestry sector loans. The U.S. should encourage other assistance agencies, particularly the regional development banks, to undertake similar programs.

- The U.S. should work with other tropical timber producer and consumer countries to promote the goal that tropical hardwoods be imported only from areas where sustained yield management is practiced. The International Tropical Timber Organization could provide the framework for this cooperation and should have full U.S. support. This effort should be accompanied by increased

assistance to tropical timber producing countries in the sustainable management of natural and plantation forests.

- The policy agenda adopted as part of any overall or broad-based Third World debt relief or restructuring should include specific measures to conserve tropical forests.

- Serious exploration should be given to the idea of an international convention to protect the world's remaining tropical forest areas. Such a convention could be the vehicle for bringing about a "global bargain" in which the national interests of the industrial countries in slowing global warming and protecting world biological resources, both promoted by halting deforestation, are reflected in relief and forgiveness of Third World external debt. A list of fifteen key tropical countries in Latin America, Asia and Africa contains virtually all of the major debtor countries as well as the countries experiencing extensive deforestation. A debt-for-nature bargain among these countries and the industrial countries would promote long-term national interests North and South. Such an agreement should also provide aid for more sustainable development projects such as renewable energy.

CONCLUSIONS

Forests are very vulnerable to the impacts of global warming, and the time-spans required for forest regeneration suggest that the consequences of global warming will take a long time to reverse. National forests are especially at risk because of their limited boundaries, and often lack contiguous open areas into which to move. Therefore, anticipatory strategies are particularly important. I strongly recommend that since significant global warming is highly likely during the next half century, the U.S. Forest Service should include global warming considerations into its forest management plans.

As part of such a strategy, the Committee may wish to consider adding carbon fixation as one of the multiple uses under which National Forests are managed. Such a step would have significant implications for current forest management practices, particularly with respect to the subsidized harvesting of timber that might more productively be left standing.

A variety of specific approaches can be envisioned which would use forests to reduce or mitigate the effects of domestic and international CO_2 emissions, thereby slowing global warming. One approach that has specific promise is the linking of specific CO_2 emitting projects in the U.S. to offsetting forestry projects around the world, as is being undertaken by Applied Energy Services with its sustainable development forestry project in Guatemala. Afforestation on federal lands and accelerated reforestation after harvesting could sequester 25 to 40 million additional tons of carbon annually, equivalent to more than 2 percent of U.S. carbon emissions. Private timberlands have the potential to fix another 28 million tons of carbon annually beyond what they are fixing now, thus offsetting another 2 percent of U.S. carbon emissions. Afforestation or reforestation of an additional 30 million acres of private land, including Conservation Reserve Program lands, could offset another 4 percent of U.S. emissions. Urban forestry might reduce carbon emissions by 1 percent. The exploitation of tree crops for biofuels production could reduce U.S. emissions of

CO_2 by a further 5 to 6 percent. Increasing the organic content of forest and agricultural soils could also offset a large but indeterminate quantity of carbon emissions. Overall, domestic forestry initiatives may well have the ability to offset or reduce U.S. CO_2 emissions by more than 15 percent, and certainly have the potential to offset most if not all of future increases in CO_2 emissions until we make the transition away from fossil fuels.

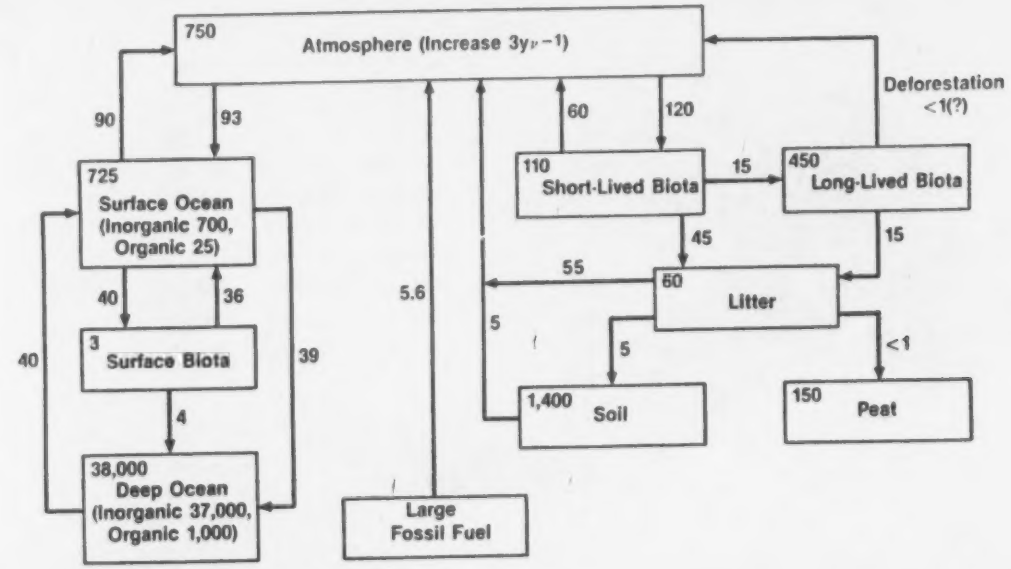
Internationally, even more could be accomplished. The types of programs outlined above for domestic application could be employed internationally to potentially reduce and offset worldwide CO_2 emissions by billions of tons. U.S. support for the Tropical Forestry Action Plan is needed, as is U.S. guidance to bilateral and multilateral aid agencies in the evaluation of projects which are likely to have significant forestry consequences.

Clearly, forestry cannot solve the entire problem of global warming, but it should play a crucial role along with energy efficiency and CFC phaseouts as we shift over the next 50 to 75 years to a non-CO_2 emitting energy base. To fail to utilize forests as part of the solution to slowing and moderating global warming will only assure that we will lose them as important economic, aesthetic, recreational and biodiversity resources.

(Figures 1 to 6 follow:)

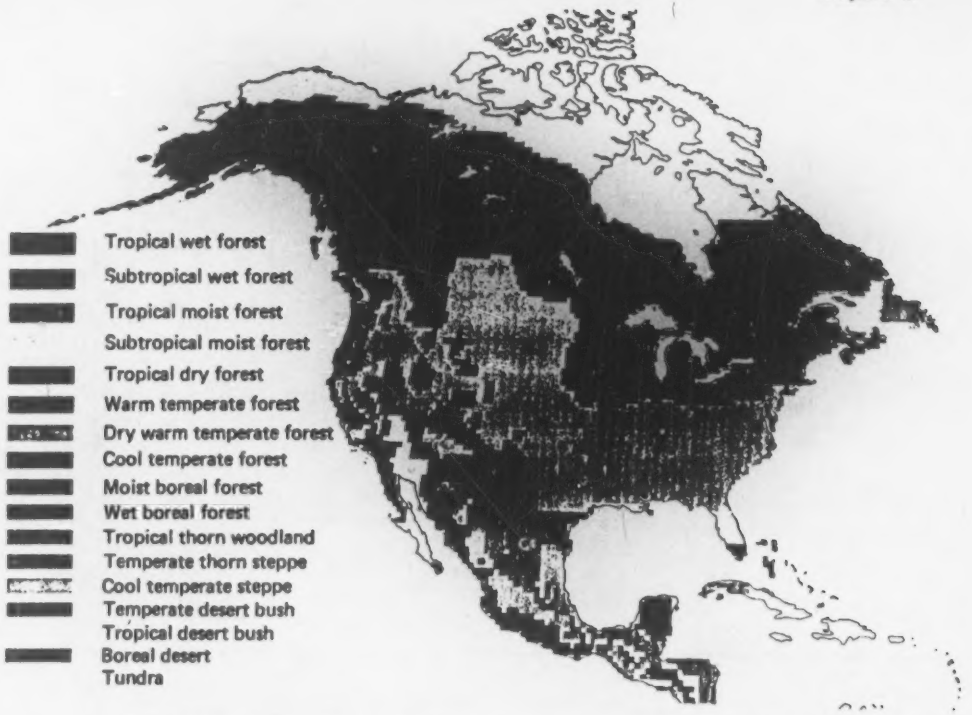
Figure 1

Carbon Cycle — 1987
(Units Gt)



Source: Gordon MacDonald
MITRE

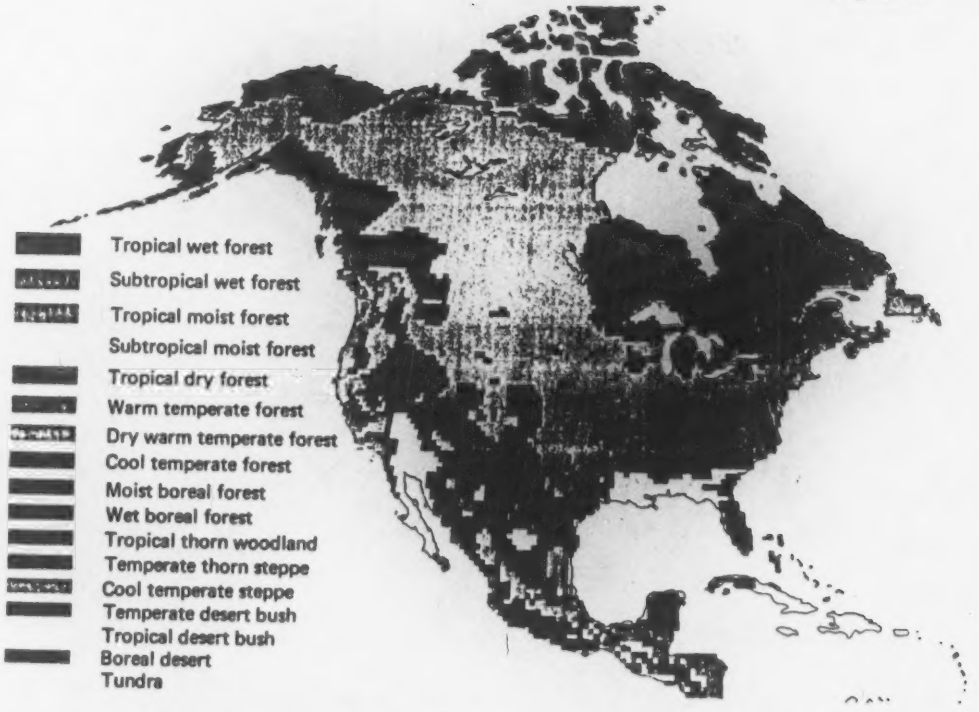
Figure 2



(*a*) Holdridge life-zone classification for present conditions of mean annual biotemperature and precipitation [58].

Source: Sustainable Development of the Biosphere
Clark, W.C. and Munn, R.C.
International Institute for Applied Analysis
page 396

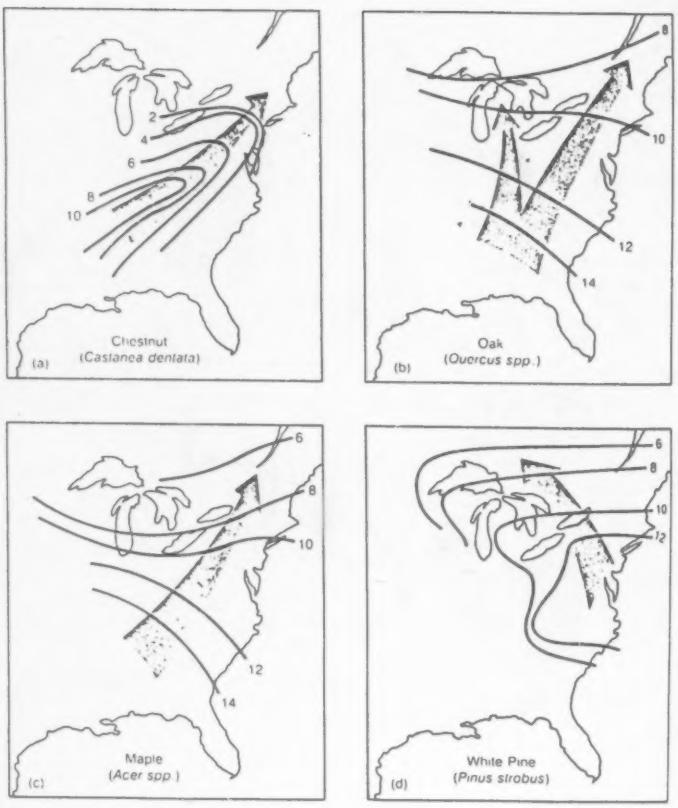
Figure 3



(*b*) Holdridge life-zone classification for doubling of CO_2 conditions of biotemperature (assuming unchanged precipitation) [58].

Source: Sustainable Development of the Biosphere
Clark, W.C. and Munn, R.E.
International Institute for Applied Analysis
page 397

Figure 4

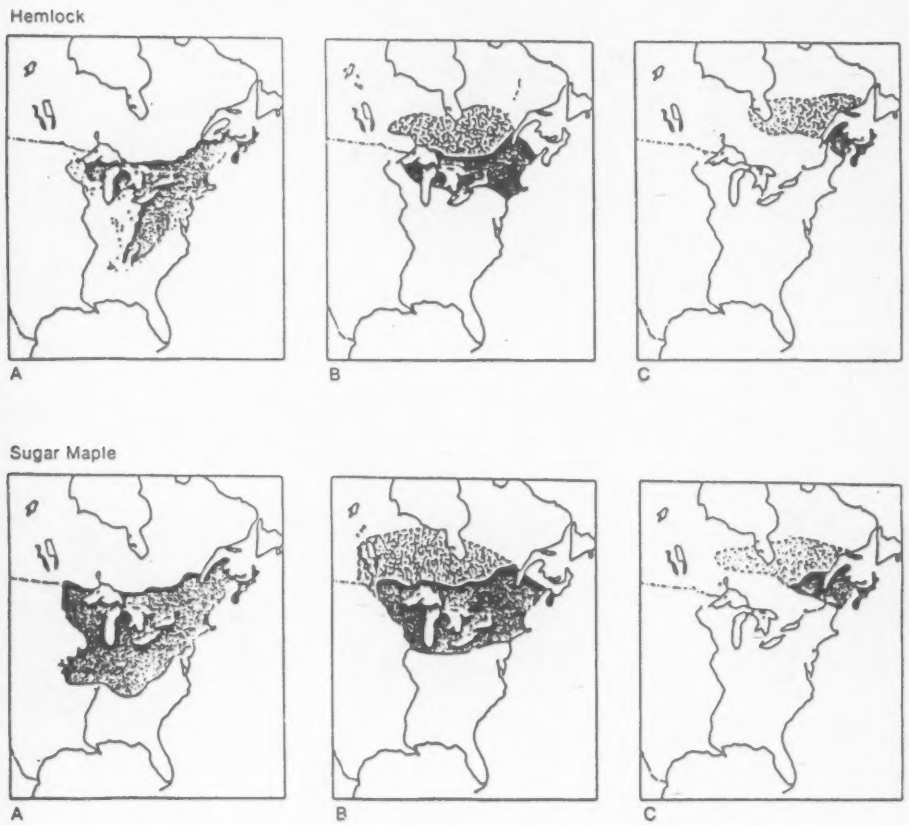


Changes in distribution of tree species during the last 10,000 years in North America. At the end of the last glacial period, as the climate warmed, tree species began to migrate northward. The history of their migration can be traced by studying pollen deposits in lakes. These graphs show the time (in thousands of years) that the pollen of chestnut (a), oak (b), maple (c), and white pine (d) first appeared at different areas of North America. From this information, one can reconstruct the general path of the migration (shown by the arrows). Chestnut, oak, and maple migrated from a refuge in the south central United States; white pine migrated from the southeast, from a refuge now offshore and under water. From a geological perspective, these species have been together in the mid-Atlantic states for a relatively short time. Chestnut reached the vicinity of what is now New York City about 2000 years ago, but oak arrived there 8000 years earlier. The forests first seen by the early European explorers (and thought to be relatively permanent associations of species) were ones that had changed in the preceding several thousand years. (From Davis, 1981.)

Source: Environmental Studies, The Earth as a Living Planet
Botkin, Daniel, B. and Keller, Edward A.
Merrill Publishing Company

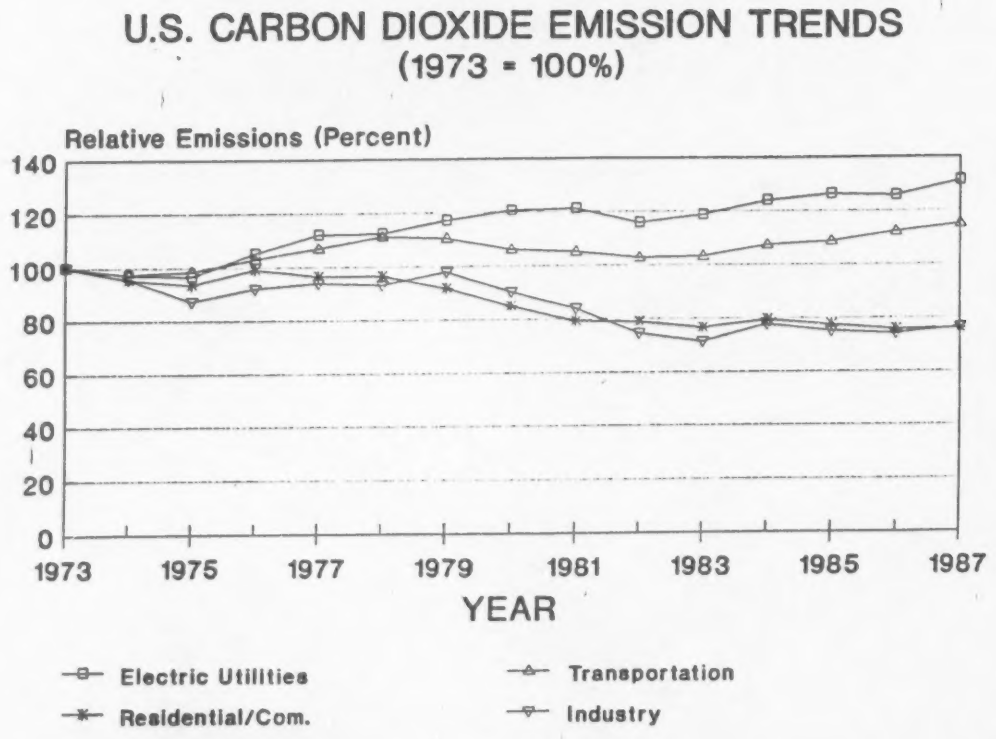
Figure 5

SHIFTS IN RANGE OF HEMLOCK AND SUGAR MAPLE UNDER ALTERNATIVE CLIMATE SCENARIOS



Source: Zabinski and Davis
From the Executive Summary draft report
Potential Effects of Global Climate Change on the United States
October, 1988

Figure 6



Source: World Resources Institute

Senator BOSCHWITZ. Thank you very much.

I think, Senator Bond, we will ask a few questions, and then we will go on to the final two witnesses.

The storage of carbon in the agricultural area—in the ground, apparently—I must tell you I do not understand how that works and how we can foster something like that in this committee. I wonder if one of you would describe to me how carbon——

Senator BOND. Conservation tillage——

Dr. MOOMAW. You mean in terms of—yes, Senator Bond is actually alluding to some of the appropriate techniques. Some of the carbon dioxide in the agricultural field is caused by agricultural practices. The traditional practices that we use expose the soil to the atmosphere where the organic content is readily oxidized. Some involves direct oxidation of those soils as they are exposed to the air, and so the soil carbon becomes carbon dioxide more rapidly. In other cases, there is more erosion, and that also breaks up the particles and makes them more susceptible to oxidation.

There are some areas, for example, in south Florida, where heavily organic soils literally are dropping an inch or so a year. You are essentially just converting that soil carbon right into carbon dioxide because of the particular agricultural practices.

The other thing that happens in forests is that when we lag behind in reforestation, those soils are much more vulnerable to oxidation and erosion. So that would be another advantage of more rapid reforestation of national forests and other lands.

Senator BOSCHWITZ. You mentioned the Government subsidies for the cutting of forests. How do we balance the need for wood for commercial purposes and the needs with respect to the atmosphere?

Dr. MOOMAW. Well, I think that at least at the present time, there are plenty of stocks of forests, both on Federal lands and on private lands, which can be cut in a way that is economically profitable. If you look strictly at the U.S. forest lands, there are stocks available now that do not require the kind of subsidies that we have been giving.

What it suggests is that in many of these cases, some of these areas are cut—they are subsidized, cut, and not replanted. In other words, they are not really considered to be prime timber-producing lands in the first place, and we are essentially going out and grabbing a free good. I mean, the forest was standing there, and so we cut it. But it costs us more to cut it than what we get back in returns for that particular timber.

Senator BOSCHWITZ. As I understand the subsidies, principally with respect to roads and things like that, you are saying that getting at forests is not economical?

Dr. MOOMAW. That is correct.

Senator BOSCHWITZ. Would you give us some percentages on output of the various sectors that you showed on one of your graphs? It shows that certain sectors were increasing in what they were turning out.

Dr. MOOMAW. Yes.

Senator BOSCHWITZ. But it did not show the percentage of the whole? Oh, that is by percentage.

Dr. MOOMAW. It is by percentage.

Senator BOSCHWITZ. But that is of increases, right?

Dr. MOOMAW. That is right. It is absolute increases. In other words, we were just setting 1973 at 100, and so we were looking——

Senator BOSCHWITZ. Yes, I understand, but the electric utilities, what percentage of the carbon dioxide do they produce?

Dr. MOOMAW. Roughly one-third. Transportation releases roughly one-third of the total emissions from the United States.

Senator BOSCHWITZ. And residential?

Dr. MOOMAW. Is about 11 percent, and the industrial sector is the remainder.

Senator BOSCHWITZ. Twenty.

Dr. MOOMAW. Twenty-some percent, yes, sir.

Senator BOSCHWITZ. I see.

I particularly enjoyed your statement. I would say to Ms. Rosenzweig that I will read your entire statement. But, you know, in a way it is a little incomplete. Demand for water and irrigation is likely to rise, and you go into quite an explanation of why rising demand for irrigation and water could place additional stresses on the water systems. But the study did not consider the changes in competing demands. But I will read it, and perhaps we can talk about it.

Ms. ROSENZWEIG. I would just like to say that Congress did not give the EPA very much time to complete its study, and we had to limit ourselves to the first cut of studies and questions. Therefore, we could only address it from the agricultural crop growth and economic side. We could not extend it into competing demands from other industries.

Senator BOSCHWITZ. But, you know, part of the difficulties of understanding this, at least on my part, is the interrelationships. I will read your testimony, and perhaps it will clarify some of the questions in my mind.

Dr. Firor, I enjoyed your testimony very much, and it gave me a sense of those interrelationships. As I approach this problem, there are growing populations and growing living standards which result in the need for enough additional energy to support this growth. You just cannot keep spewing that stuff into the atmosphere over a long period of time without doing something. I am just a simple plywood peddler. I may have to go into a different trade after listening to Dr. Moomaw. This line of work is rather irregular——

Senator BOND. It also generates certain gases. [Laughter.]

Senator BOSCHWITZ. I would never say anything like that, but it does. We do want to understand the interrelationships associated with global warming, and we do want to get out ahead of the curve so that we are not sitting here some years from now and wondering what to do. Perhaps we can influence the result. That is why I was so particularly pleased that the chairman held this hearing and why I got involved in this issue early on.

Senator Bond.

Senator BOND. One of the conclusions that is apparent from all of the discussion is that perhaps when, over the past few years by some conscious decisions, some unintended consequences, or perhaps other inadvertent actions, we decided not to go forward with nuclear power in this country, we may have at that time over-

looked the very real problem that fossil fuel, electrical generation produces. We look at countries like France, which has a very large component of nuclear power in its energy production base—I do not know what it is, but I believe it is very significant.

From your standpoint, the three of you, have we missed the boat? Did we make a wrong turn in the road?

Dr. FIROR. It seems to me that we have in front of us a readily available and very cheap source of energy to replace fossil fuel, and that is end use efficiency. If we all——

Senator BOSCHWITZ. Is what?

Dr. FIROR. End use efficiency. If your car and my car got 40 miles to the gallon rather than 20, if we put good light bulbs in here rather than the inefficient ones, if we insulate our houses, we could save very large quantities of energy at very low cost.

Now, someday, if we go hard at that, we will use up all of those efficiency improvements. You cannot be better than 100 percent efficient. You cannot even get to that. So we will have to look ahead and say: What do we replace fossil fuel with after we use it as efficiently as possible? After we have gotten this cheap, easy thing out of the way, what do we do?

It would please all of us if there were waiting on the shelf alternate supplies that you could count on. Nuclear energy has to be a candidate, but it has failed to achieve enough public acceptance. When I talk to executives of power companies, they say the last thing they would do right now is sign a contract for a nuclear powerplant because it is so much trouble and is so expensive and no one knows what to do with the waste.

In my State, the Governor panics because there are boxcars piling up on the side because no one knew where to store the waste from it.

So it would be nice if it were ready, but it is clear that in this country it is not ready. France seems to be an exception, but it almost stands out in the world as a country that thinks it is ready. Other countries do not.

Senator BOSCHWITZ. But who is right? Are the French right? Quite aside from the public perceptions—of nuclear energy—should we rise above the public perceptions? Is nuclear energy a source that we should look to?

I read an article, "The Case Against Nuclear Energy," and the point was that it was no longer economically effective and that people would not accept it. I mean, should they?

Dr. FIROR. It seems to me there are three problems: One is the fundamental safety issue; two is the waste disposal issue; and three is the possibility of proliferation of nuclear materials to people you do not want to have them.

Those three problems, in my opinion, sir, have not been adequately solved in this country to make it today a source that one can count on rapidly to replace fossil fuel. The cost, perhaps because of those three problems, is also quite high. So in my view, we need now to reexamine all possible sources of alternate energy—nuclear, photovoltaic, wind, what have you, biological sources, biomass sources—so that we can begin to replace fossil fuels as we use up this conservation and efficiency source which is so available and so inexpensive that that must be our first attack on the problem.

Senator BOND. Would either of you care to comment on that?

Dr. MOOMAW. I would just reinforce what Dr. Firor was saying. It seems to me that not only in the United States, but in most of Europe now outside of France, the current generation of nuclear power is not going to be expanding much more. In the United States, I think there are only something like 16 more powerplants that are even in the regulatory pipeline, and I think it is generally agreed that probably only half a dozen of those will ever really be built. So we are, I think, at the end of the current generation of nuclear power in the United States. What that suggests is that if there is to be a contribution from nuclear power in the future, we are looking at a new set of designs, and there are people who have such designs in mind. And there is a modest amount of research being done on those.

What that means to me is that we cannot expect nuclear power to be a big contributor beyond what it already is, and actually, its contribution today is relatively small. I mean, electricity is not everything in the United States, and it is not everything in the world. Even within the United States, where we have just under 20 percent of our electricity coming from nuclear power, it only offsets a relatively small percentage of the carbon dioxide releases to the atmosphere.

But what this means is that the next generation of nuclear power probably will not begin to make significant contributions—assuming that everything goes well and we develop it right—for another 15 or 20 years. At that point, nuclear must be compared with other technologies that will have been developed, such as solar and wind and photovoltaic generated hydrogen or whatever the technology is going to be.

I think at that point it will be a question of which of those sources is the most economically competitive and which is most acceptable both to the investors, the utilities, and to the public. So what I would prefer to see is that we begin now doing the kind of energy research and development on the supply side that will give us the options 15 or so years from now, because I think that is realistically when we are going to be seeing any of these making a difference.

Senator BOND. Do you see fusion energy as likely to be more desirable and effective than fission energy?

Dr. MOOMAW. I am not a fusion physicist, but the thing I have noticed about fusion is that it will always be economically viable about 30 years after the time that the person making the statement is making the statement. It is very far in the future. I would not discount it 100 percent, but I also would not count it as something that is going to be there when we need it.

Senator BOND. To follow up on Senator Boschwitz' comments, I think that clearly there are the considerations, the concerns that you have expressed with respect to safety, proliferation of nuclear materials. But to a great extent, the reason why power executives and others are saying no way we would develop any further nuclear sources are the fact the elected officials, interest groups and others have brought lawsuits and essentially imposed very heavy costs on the nuclear industry. To the extent that those are not solely related to the essential problems, is it not appropriate that

the discussion of the warming effect include a call for the non-CO_2 generating forms of energy, or releasing forms of energy?

Dr. FIROR. Certainly, we must have non-CO_2 forms of energy in the long run. The question is one of, it seems to me, economics. Right now, if you say I want to reduce carbon dioxide by as much as possible by the year 2005—that is a nice number; the International Conference has recommended that the world drop by 20 percent CO_2 emissions by that date—how do you get from now to that date in the most cost-effective way? Nuclear does not play a role in that. It is too expensive today, even if you allow for an accelerated licensing that would get around some of the problems that you have. It just costs too much compared to the alternative of better light bulbs.

It seems strange to compare those two things, but right now that is the competition. In the longer run, as Dr. Moomaw says, we have to have new sources. I know of two research efforts to make the next generation of nuclear power that would avoid these so that we have less controversy and make it something that could be introduced. Not before the end of the century, is the judgment of most of the people working on those, would they be ready to say we now have a design that solves these problems and we can go ahead with a nuclear industry which is sizable and can make a big difference.

Dr. MOOMAW. Senator, if I may follow up on that, it was interesting at the press conference when this project for offsetting carbon dioxide emissions from a coal plant was held. The CEO of that company, Dr. Roger Sant, made the point that the extra cost of planting trees in Guatemala to offset emissions from his coal plant was about one-tenth of a cent per kilowatt hour, and that that gave him an advantage over nuclear power of 4 cents a kilowatt hour.

His argument was that in simple economic terms we should look at forestry as a way of at least using coal and other fossil fuels during a transition period. Obviously, you need to offset emissions from gas- and oil-fired plants as well.

Senator BOSCHWITZ. Pardon me, Senator Bond, but as I remember that example, it removed more CO_2 over 100 years, but the CO_2 was produced in the atmosphere in a relatively shorter time, by 40 years or whatever it was, by the powerplant. Is that correct?

Dr. MOOMAW. Well, no. The goal of the project was to fix the 15 million tons of carbon that would be emitted by it during the 40-year lifetime of the powerplant. Now, what will happen is this: The first few years the trees are not that big and they are not fixing very much carbon dioxide. In the middle years, trees are actually growing faster and taking up carbon dioxide faster than the powerplant is releasing it. Then by the end of the power station's lifetime, the trees have slowed down their growth rates and are not absorbing as much carbon dioxide as is being released. But the idea was that over the 40-year period the planted trees would absorb the full dose.

Senator BOND. We have approximately 28 to 30 million acres in CRP, and we are going to have to consider what happens to that CRP land at the end of 10 years. I think that is one of the tough problems we are going to have to grapple with. We do have a strong program for incentives. And say we planted all of that to

forest land, that which is not right now, do you have any idea what kind of impact that would have on CO_2?

Dr. MOOMAW. Our estimate is it would probably offset about 2 percent of annual U.S. CO_2 emissions. Now, that does not sound like a lot, but that is of the order of what our increases are every year. It would offset, for example, all of the additions from all of the fossil fuel powerplants that are likely to be built over the next decade in the United States.

I think we have to realize we are going to be grabbing for every tenth of a percent reduction we can from wherever we can get it to slow CO_2 growth. So, you know, my initial reaction was the same as yours: 2 percent, why bother? But I think when you really analyze it, we have got to find 2 percent here and 2 percent there, wherever we can get it. I think that this is a significant 2 percent.

Senator BOSCHWITZ. Are other things affecting the other 98 percent as well? Are other things mitigating it?

Dr. MOOMAW. Well, we do not have active programs to mitigate the other 98 percent.

Senator BOSCHWITZ. Not natural trees?

Dr. MOOMAW. No. I am saying this is in excess above what is being——

Senator BOSCHWITZ. The increase.

Dr. MOOMAW. Right. This is in excess of what is being absorbed.

Senator BOSCHWITZ. I see.

Senator BOND. One final question in the areas of desert. If we are able, through genetic engineering, to develop what might be considered normally more wetland tree bases that can live and can adapt to a desert climate, is that a productive area of exploration? If we can grow a different kind of forest in desert land, it would seem to me that that is a tremendous acreage opportunity if the genetic engineering can permit the development of trees that could subsist in desert.

Dr. MOOMAW. I think adapting to future conditions, some of that will be done through genetic engineering. Just a suggestion specifically for this committee, which I did not have time to go through—it is in my written testimony—is that as the Forest Service develops its 50-year plan for managing forests, to think ahead to what kind of species ought to be planted in the future in those particular areas. Secondly, I think there is some work going on in trying to develop more dryland species. Again, every bit of that is going to be helpful, but no one part of it by itself can solve the whole problem, I guess is what I would conclude.

Ms. ROSENZWEIG. Bioengineering might be important in the crop area to develop crops which are adapted to the warming. Developing crops with drought tolerance and heat tolerance would also be an important motivation.

Senator BOSCHWITZ. Ms. Rosenzweig, a final question, if I may. What lessons do your studies have with respect to farm policy? What impact does farm policy have on what you have studied? And what are the needs of a farm policy?

Ms. ROSENZWEIG. It is a question of defining vulnerabilities and ensuring the ability of farmers to be flexible to adapt to the possible changes. As the Congress evaluates agricultural policies, it should make sure that farmers will be able to switch crops easily.

For example, there should not be restrictions on crop types associated with certain commodity policies, so that the flexibility in their adaptation is encouraged.

There is a lot to be done in research. Bioengineering is a possibility and continued development of drought- and heat-tolerant crops and species.

Also, one of the most crucial areas in research is the projection of the potential climate change on the international food trade. How will other countries' agriculture respond? And how will this effect the U.S. food trade?

Finally, in the research efforts, we need to continue to improve our ability to estimate the climate change and its impacts. To follow up on your question about the interrelatedness: in the research area there is a lot of focus on monitoring the atmosphere with the increases in the trace gases. There is also a lot of emphasis on modeling the climate to see how the climate may change. There has been less emphasis on studying the impacts of climate change, and the impacts are where all these interrelationships play out. We need to study much more what these interrelationships are and what the effects of potential climate change may be on all our systems.

Senator BOSCHWITZ. Well, you sound like you are a proponent of decoupling, which is fine with me.

I now have to call the next panel. I did not realize that Senator Bond was leaving, and I have to go to a doctor's appointment that I will not be able to miss. So Dr. Bentley and Ms. Fisher, if you would please come forward.

Another Senator may come and extend your testimony time, but I must ask you to please limit your time to 10 minutes each. Go ahead, Ms. Fisher.

STATEMENT OF LINDA J. FISHER, ASSISTANT ADMINISTRATOR FOR POLICY, PLANNING AND EVALUATION, ENVIRONMENTAL PROTECTION AGENCY

Ms. FISHER. Thank you, Senator.

What I wanted to do today, given the short amount of time, is focus on a few issues that the previous witnesses had not had an opportunity to discuss. I want to talk with you about what the major greenhouse gases are, what their sources are, and what countries emit them. I will briefly talk about the effects report that our Agency has done, although I think the other witnesses covered most of the findings of that pretty well.

Last, I want to talk with you about what activities the U.S. Government has under way to deal with the global warming problem.

I am going to refer to some charts over here to illustrate some of the points I want to make. The first chart shows the international regional contributions to greenhouse gases.

Greenhouse gas is perhaps one of the most international environmental problems that we have had to face to date. This chart demonstrates the contribution different countries make to global warming. As you can see from the pie chart, the United States is the biggest contributor, contributing approximately 21 percent of the greenhouse gases. The European Community contributes 14 per-

cent; the Soviet Union, 14 percent; China, 7 percent; Brazil and India, 4 percent apiece; and the rest of the world, 36 percent.

This chart is important because it brings home the concept that if we are really going to deal with lowering emissions of greenhouse gases, we have to act internationally. The United States can play a leadership role, but the United States cannot solve the problem alone.

Now let me turn to the individual greenhouse gases and talk a little bit about the sources of those gases. The first one is the one some of the other witnesses talked principally about—carbon dioxide. It comprises approximately 50 percent of the problem. As you can see from the pie chart, the bulk of that, approximately 75 percent, comes from the burning of fossil fuel. The rest of it predominantly comes from deforestation.

The chart also indicates what countries are the major contributors of these different sources. Fossil fuel contribution is——

Senator BOSCHWITZ. You do not have these charts in your testimony.

Ms. FISHER. They should be in there.

Senator BOSCHWITZ. OK. Go right ahead.

Ms. FISHER. I will not be following all of those because of time.

The fossil fuel contribution largely comes from the United States, the Soviet Union, and China. The major contributors to deforestation are Brazil, Indonesia, and Colombia, again indicating the need to interact internationally to lower the emissions of CO_2.

The next chart indicates the trends in emissions of CO_2 from fossil fuel consumption. As you can see, the U.S. again, China, and the Soviet Union are the principal contributors, but I think it is important to point out that the U.S. and Western Europe's contribution is on a decreasing trend. The Soviet Union and China are increasing their use of fossil fuel. The governments of those two countries have targeted economic development as one of their principal issues. They intend to use principally coal to fire the energy source for this economic expansion. For those that have a concern about greenhouse gases, that becomes a very important issue—that their increased use of fossil fuel will have a dramatic effect on greenhouse gases.

The next chart focuses on methane. Methane comprises approximately 18 percent of the contribution to global warming. The principal sources of methane are fossil fuel, landfills, rice production, biomass burning, and domestic animals.

With CO_2, our principal sources were two: the use of fossil fuel and deforestation. With methane, we have a large number of different sources. So policy options to deal with reducing methane will be a lot more complex. Additionally, the countries that are leading contributors of methane to the atmosphere is a different mix than we saw before. Leading producers of rice include India, China, and Bangladesh. The larger producers of domestic animals are India, the USSR, and Brazil.

The next chart focuses on a third greenhouse gas, and that is chlorofluorocarbons, or CFC's. CFC's comprise approximately 14 percent of the problem. They are the gas that the Montreal Protocol addressed, and that protocol provided for an international agreement to phase down the use of CFC's. So it is the one green-

house gas that the world has acted in an international sense to reduce.

The next chart lays out for you the effects report that the agency is in the process of completing. The report was issued in draft recently. It has been reviewed by our Science Advisory Board. It is undergoing interagency review. We will be incorporating many of those comments into the final report, which will be back up to Congress by the end of the year. This and the stabilization report, a report which reviews policy options to reduce greenhouse gases, will also be up to the Congress, hopefully early next year. Senator Leahy was a principal proponent of that in helping the Agency get funding for it.

Let me briefly review some of the findings that we had in that report. Some of these you have heard already from the other witnesses, so I will try to move through them quickly.

First, the report was divided into two components: a national look and then specific regional looks. Nationally, we looked at things such as sea level rise, water resources, agriculture, forests, and human health. Let me focus first on the agricultural effects that we found.

As the other witnesses indicated, there will be uncertain effects on crops when you look nationally. In certain parts of the country, the crop yield will increase. In other words, the climate and temperature will improve the opportunity for farmers. In other parts of the country, it will not be as conducive to a strong agricultural economy. Therefore, when you look nationally, the net impact is still uncertain.

Additionally, we tried to look at the interaction between increased CO_2, one of the greenhouse gases, which provides a fertilization effect and, in fact, would help crops grow; played that off against the adverse effects from the heat and the dryness; and, again, we found that there is some uncertainty, although the Northern and Northwest parts of the country would be more positively affected and the South and Southeast would be more adversely effected.

Additionally, we found that irrigation practices would be affected. The demand for increased water and irrigation would rise. The one question that we did not address completely and we would need to do additional studies is with the increased demand for water. Will, in fact, the water be there to provide to the farmers? So that is an area that we need to do additional work on. But we know that irrigation demands will go up and perhaps mitigate some of the adverse effects—if, in fact, the water supply is there—that warming might bring.

We also looked at water resources. We found that the high temperatures will reduce snowpack in certain parts of the country and, therefore, change the seasonality of runoff and also increase the amount of evaporation.

Again, we found an increased demand for water through not only irrigation but domestic consumption, powerplants, and other uses. We also found that water quality in many basins could change. To the extent the water level goes down in rivers and streams, the water quality would be adversely affected. To the extent water, at

least in certain times of the year, may increase, the water quality could benefit.

In terms of forests, I think Dr. Moomaw presented you pretty much with the effects that we found; that is, that the forest mix will change. Some areas of the country which currently have forests may be turned into savannas or grasslands, and the overall range of forestry available in the United States could decrease.

Let me quickly turn to some of the regional impacts that we found.

Senator BOSCHWITZ. We are almost out of time.

Ms. FISHER. Well, why don't I not do the regional effects? Because what I do want to talk to you about is what EPA and other agencies are doing currently to address this issue.

Senator BOSCHWITZ. Trying to regionalize the impact of all this is apparently fairly difficult.

Ms. FISHER. It is very difficult.

Senator BOSCHWITZ. And speculative. I would say to the staff of the chairman that we ought to have a more targeted hearing; for instance, entirely on conservation. Perhaps I accept more than some that global warming is a problem and that we ought to start moving on it, and not try to define exactly how it is going to affect us here and there. I will talk to the chairman about having a more targeted hearing.

If you would conclude, please, Ms. Fisher.

Ms. FISHER. Let me summarize for you, then, the different activities that we at EPA and some of the other agencies have under way, because they will provide you an opportunity perhaps to explore those in your other hearings.

First of all, the U.S. Government is acting in a coordinated way to develop a comprehensive research plan to resolve some of the uncertainties associated with global warming.

Second, we are also interacting with the different agencies to address the policy options that we could undertake to do two things: one, to limit the emissions of greenhouse gases; and, second, how we would go about adapting to warming when it occurs. And some of the things that you questioned the other witnesses about—improved technology, biotechnology and that sort of thing—offer opportunities to adapt to warming.

Last, as you know, because you were in Geneva, the United States is participating on an international scale with the other countries of the world. The United Nations Environmental Program has set up a process for countries to focus on three areas similar to the United States. There is an international science group that will try to define what kind of uncertainties and certainties we have in the scientific arena. There is a second work group to look internationally at the effects of global warming. We have done it domestically; they will do it internationally. Lastly, there is a work group that the United States is going to be the lead of that will explore policy options and the best opportunities, the most cost-effective opportunities for governments, the United States as well as others, to reduce emissions of greenhouse gases in their own countries.

[The prepared statement and attachments of Ms. Fisher follow:]

FINAL 12/1

TESTIMONY OF
LINDA J. FISHER
ASSISTANT ADMINISTRATOR
FOR POLICY, PLANNING AND EVALUATION
U.S. ENVIRONMENTAL PROTECTION AGENCY

December 1, 1988

Good morning. I am pleased to be here to discuss the Environmental Protection Agency's Global Climate Change Program.

The Issue

Greenhouse gases, such as water vapor, carbon dioxide, nitrous oxide, methane, and others, occur naturally in the atmosphere. They serve as a figurative thermal blanket, allowing solar radiation to pass through the atmosphere and strike the earth's surface, while absorbing some of the infrared radiation emitted back from the surface. This selective absorption of long-wave radiation warms the atmosphere and gives us our present climate. If there were no greenhouse gases, it is estimated that the earth would be approximately 30°C colder. If the concentrations of greenhouse gases are increased, the atmospheric temperature will increase.

There is scientific consensus that increases in atmospheric greenhouse gas concentrations will result in climate change. Atmospheric concentration of carbon dioxide have increased approximately 25 percent since about 1860, in part due to fossil fuel combustion and industrial and agricultural activities. The National Academy of Sciences' Nirenberg Study Commission has estimated that the effective doubling of the concentration of carbon dioxide in the atmosphere could eventually lead to a global warming of 1.5 to 4.5°C. However, considerable uncertainty exists with regard not only to the timing, but also to the ultimate magnitude of any global warming. In addition, there is great uncertainty about how climate variability and regional climate patterns may change.

Sources of Greenhouse Gases

Since the onset of the industrial revolution, man's activities have added to the concentrations of naturally-occurring greenhouse gases. A diversity of sources have contributed to this increase, including the burning of fossil fuels, deforestation, and, more recently, the use of synthetically produced chlorofluorocarbons (CFCs) (see EXHIBITS 1 and 2). Expanded agriculture has also contributed to increased greenhouse gas emissions. Agriculture contributes greenhouse gases to the atmosphere from several

sources. Methane emissions result from the digestive process in livestock and from the cultivation of paddy rice. The increase in the global cattle population has been identified as a contributor to the increasing trend of atmospheric methane. Nitrous oxide emissions result from the use of nitrogen fertilizers. The nitrification and denitrification processes in fertilized soils result in the emission of nitrous oxide to the atmosphere. Increased use of nitrogen fertilizer causes this to be an increasing source of the gas globally.

Greenhouse gases are emitted from both the developed and less developed countries. Approximately seventy-five percent of CO_2 emissions from anthropogenic sources come from the burning of fossil fuels, and twenty-three percent result from deforestation -- largely in tropical countries (see EXHIBIT 3). Western Europe and North America account for approximately forty percent of fossil fuel emissions, but since the early 1970s, their emissions have remained relatively stable. In fact, the United States' fraction has been decreasing. The Soviet Union and Eastern Europe, the People's Republic of China, the Pacific rim countries and the developing countries contribute approximately sixty percent of fossil fuel emissions, but most importantly, their share is rising (see EXHIBIT 4). With regard to other greenhouse gases, approximately seventy-five percent of the CFCs are produced in North America and Europe, while major sources of methane are associated with rice production in Asia (see EXHIBITS 5 and 6). Thus, all countries contribute to greenhouse gas emissions and share some responsibility for their continued growth.

EPA's Interest

EPA is involved in the global climate change issue for a number of reasons. First, EPA has traditionally examined the effects of pollution on human health and the environment and options to reduce emissions of those pollutants. For example, under the Clean Air Act, we study the emissions, transport, exposure, and ultimate effects of air pollutants. We also examine technological options to limit emissions and when necessary, regulate these emissions to protect the environment.

Second, EPA has experience in dealing with global environmental issues. For example, EPA played a leading role in analyzing the effects of stratospheric ozone depletion and in developing options to limit emissions of such ozone depleting chemicals as CFCs and halons. With U.S. domestic policy under the Clean Air Act and international policy proceeding in parallel, international action eventually led to the adoption of an unprecedented global environmental agreement, the Montreal Protocol on Substances that Deplete the Ozone Layer.

Although the Agency has studied the effects of global warming for several years, its current efforts on global climate change have been stimulated by two Congressional actions. The first is a Congressional request made in 1986 to develop two reports on global warming. The request stated that a report on policy options for stabilizing greenhouse gas emissions should be prepared and

should examine options to reduce emissions of a number of greenhouse gases from energy use, CFC production, deforestation, and other activities. The request also asked EPA to prepare a report on the health and environmental effects of climate change.

In response to the Congressional Directive, EPA has a draft report that assesses the effects of global climate change on forests, lakes, wetlands, agriculture, human health, and other aspects of the environment. The focus of the Effects Report is on the United States. The Report examines how hydrology, agriculture, forestry and infrastructure may change in four regions of the United States: the Southeast, the Great Lakes, California, and the Great Plains. These regions were chosen because of unique characteristics that each exhibits. The Southeast has unique ecosystems and much coastal activity, forestry, and agriculture. The Great Lakes are the largest source of fresh water in the world. California is a highly populated area with a high demand for, and a limited supply of, water. The Great Plains are among the most productive agricultural areas in the world.

Our overall objective is to use the best available models, atmospheric scientists, and researchers to assess the effects of climate change. Yet, we recognize that precise quantitative forecasts of impacts are beyond the capabilities of current science. The existing general circulation models cannot be used to make precise predictions -- especially at the regional level. We are therefore looking at a range of potential impacts (i.e., scenarios) in order to provide a sense of the sensitivities of different effects to changes in temperature and other variables. These scenarios will not necessarily bracket the entire range of potential impacts.

The draft Effects Report attempts to achieve several objectives. Despite the scientific uncertainties in the state of the art, we attempt to the ranges of possible future effects that may occur under climate change scenarios, as well as establish qualitative sensitivities of different environmental systems and processes to changes in climate. We also describe qualitative linkages between the effects observed in different regions mentioned above.

EPA has actively encouraged participation of other federal agencies and the broader scientific community in the research process leading up to these reports. EPA held several workshops with scientists to discuss creation of climate change scenarios and effects projects. Over 50 leading scientists contributed studies to the effects report. The draft EPA effects report is undergoing review by the Science Advisory Board, the Committee on Earth Sciences, and other federal agencies. We are reviewing the comments we received and hope to issue a final report later this year.

The second Congressional action is the Global Climate Protection Act of 1987. Included in its provisions is the requirement that,

> The President, through the Environmental Protection Agency, shall be responsible for developing and proposing to

Congress a coordinated national policy on global climate change.

The Act also provides for the Secretary of State to seek further international cooperation on limiting global climate change. In addition, the Act requires that the Secretary of State and the Administrator jointly submit, by the end of 1989, a report analyzing current international scientific understanding of the greenhouse effect; assessing U.S. efforts to gain international cooperation in limiting global climate change; and describing a U.S. strategy for seeking further international cooperation to limit global climate change. This is a very broad mandate which will require close cooperation with other agencies (including NASA, NOAA, COE, and the Departments of Energy, Agriculture, Interior), the National Climate Program Office, and the Domestic Policy Council. The Act encourages coordination of domestic and international climate activities with research and impact analyses that are consistent with policy goals.

Our Office of Research and Development (ORD), in addition to supporting the Agency effort to respond to Congress' request for these two reports, is also responding to a request from the Administrator to improve its institutional capabilities to begin work in the global climate change arena. We are preparing a comprehensive inter-agency plan that will define more clearly the Agency's research role in developing better emissions factors, identify the ecosystems that are sensitive to climatic variation and may be at risk, and establish possible relationships between global and regional changes. A plan for EPA's research efforts will enable us to interact effectively with existing efforts in other Federal agencies and with scientific research and assessment activities in domestic and international forums. ORD is an active participant in OSTP's Committee on Earth Sciences, the group coordinating the Federal Global Change research effort.

EPA's International Activities

Let me turn to the subject of EPA's role in international activities, because no single country alone will be able to decisively affect the greenhouse gas problem.

Several international "actors" are currently involved in the global climate change arena. The United Nations Environment Programme (UNEP) is responsible for conducting climate impact assessments. The World Meteorological Organization (WMO) is supporting research and monitoring of atmospheric and physical sciences. The International Council of Scientific Unions (ICSU) is developing an international geosphere biosphere program that is focusing on the biological sciences.

EPA is also participating in the international arena in both multilateral and bilateral initiatives on climate change. On the multilateral level, we are working with the Department of State and other agencies to support the Intergovernmental Panel on Climate Change, set up by UNEP and WMO last summer. Dr. Frederick

Bernthal, Assistant Secretary of State for Oceans and International Environmental and Scientific Affairs, led the U.S. delegation to the first meeting of this panel November 9-11 in Geneva. The panel, which has already begun to function, will help ensure an orderly international process of activities on global climate change. Specifically, it will channel efforts into two tracks: the first to assess the state of scientific knowledge on the issue; the second to assess social and economic effects from a warming and potential responses.

EPA participates in agreements in environmental protection with several nations, including the Soviet Union and the Peoples' Republic of China. We have a strong bilateral relationship with the Soviets through the 1972 US-USSR Agreement on Cooperation in the Field of Environmental Protection, under which agreement we have conducted joint research on a wide variety of environmental issues.

Several U.S. technical agencies, including EPA, have had discussions with the U.S.S.R. under the Environmental Agreement and other agreements on the following topics relating to global climate change: 1) future climates; 2) climate and paleoclimate studies in the Arctic; and 3) measuring methane and ozone changes in Arctic and Antarctic regions. Additionally, EPA has had discussions with the U.S.S.R. on the overall U.S. program relating to global climate change, and anticipates a similar presentation by the U.S.S.R. These efforts should make an important contribution to the international assessment, led by UNEP and WMO, on global climate change.

Last year, EPA also signed a bilateral agreement with the Peoples' Republic of China, which included specific provisions on climate change. Potential areas for cooperative research include exchange of information and development of data on future energy development paths, emissions from rice fields and other sources, and concentrations of trace gases in remote regions. In general, these bilateral agreements provide an excellent opportunity to facilitate international cooperation and mutual understanding of this issue.

Design of the Effects Report to Congress

Let me now focus on EPA's effects report to Congress (Exhibit 7). To respond to the Congressional request for a report on the effects of a global warming, EPA held workshops with atmospheric scientists to discuss how global climate change models should be used in impact analyses and with ecologists, hydrologists, and forestry and agricultural specialists to identify topics for this study. A major purpose was to bridge the gap in our ability to relate a rise in average annual surface temperatures to effects on forests, agriculture, and other resources. As a result of the workshops, EPA decided to take outputs of climate models and compare them to what is known about historical climate patterns and to select plausible scenarios as predicted by these models. These scenarios of climate change can then be used to analyze the potential impacts on sea level rise, water resources, agriculture,

forests, biodiversity, health, air pollution, and electricity demand on a regional and national scale. As mentioned earlier, EPA decided to conduct regional analyses for the Southeast, the Great Plains, California, and the Great Lakes. These regions were chosen because of their climatological, ecological, hydrological, and economic diversity.

The effects report is using regional data from atmospheric models known as general circulation models (GCMs) as a basis for climate change scenarios (Exhibit 8). The GCMs are large models of the ocean-atmosphere system that provide the best scientific estimates of the impacts of increased greenhouse gas concentrations on the climate. But these GCMs have significant limitations. The GCMs generally agree concerning general global and latitudinal increases in temperature, but they disagree concerning other areas such as the location of hydrological change, and regional climate change and variability. Preliminary results of these models, for example, suggest that more annual rainfall is likely across the country, but which regions get more or less rainfall and when is less certain. The smaller the regions studied, the more divergent the results of the different models become. This is particularly true when the surface conditions are for land (not ocean) and in the summer season. Nonetheless, while these models may not be providing accurate estimates of future conditions, they should be useful in projecting possible scenarios. The GCM results should not be considered to be predictions, but as scenarios of future climate change. Because the regional estimate of climate change by GCMs vary considerably, the scenarios are used to identify the relative sensitivities of a variety of systems to global warming and a range of possible effects. The majority of our studies analyze sensitivities when the equivalent of a doubling of CO_2 occurs, but some studies also looked at changes over time. The scenarios also assume that variability in the future will not change from recent decades. Changes in the frequency of events such as heat waves, storms, hurricanes, and droughts in various regions would affect the results to be presented in this report and could improve or worsen the effects

How quickly climate may change is elusive, because scientists are uncertain both about how rapidly heat will be taken up by the oceans and about some climate feedback processes such as cloud formation. Generally scientists assume that current trends in emissions will continue and that climate will change gradually over the next century, although at a much faster pace than historically. Some scientists have indicated that the impact of global warming may be felt as soon as the next decade, but the full effect of the equivalent doubling of CO_2 probably would not be experienced until after 2050. Other scientists suggest that the current structure of the GCMs, which are based on a surprise-free ocean-atmosphere system, could be wrong and that abrupt changes are possible. Indeed, if climate changed more rapidly than estimated, the results will be more dynamic and dramatic.

Similarly, the methods used to estimate impacts (for example, how forests might change) also have limitations. We have no

experience with the rapid warming of 1.5 to 4.5°C projected to occur during the next century. We cannot simulate in a laboratory what will happen over the entire North American continent. We cannot be certain that a forest will be able to migrate, whether fish will find new habitat, how agricultural pests will proliferate, or how impacts will combine to create or reduce stress.

The Potential Effects of Climate Change

Let me now highlight several of the impacts identified in the effects report. In particular, I will focus on sea level rise, agriculture, and forestry effects. Let me emphasize once again, however, that there are numerous sources of uncertainty about these effects and the scenarios they're based on.

The EPA study is based on the assumption that global warming could raise sea levels as the warmer ocean waters expand, mountain glaciers melt, and the ice sheets of Greenland and Antarctica melt and discharge ice into the oceans. Such a rise could inundate wetlands and lowlands, exacerbate flooding, and increase the salinity of surface and ground water. In California, for example, sea level rise could increase the salt concentrations in San Francisco Bay. Saline water in the Sacramento San Joaquin River Delta could migrate upstream. Sea level rise could increase the size of the Bay.

The effects of climate change on forests will be primarily driven by changes in temperature and evaporation. There may be a reduction in forest ranges. Dieback begins with as little as a 1°C temperature increase. Southern boundaries might therefore move northward due to dieback as a result of temperature and precipitation changes. Northern boundaries might shift northward, but potentially at a slower rate than the sourthern boundary dies back. There might also be changes in forest species composition. For example, such species as cedar and birch may no longer exist in the lower 48 states. However, climate is only one factor in determining the potential boundary shifts. Soil composition can play an equal or even more important role.

Climate change may affect agriculture in different ways. Increases in temperature and changes in precipitation patterns can reduce agricultural yield. However, the direct fertilization effects of increased atmospheric CO_2 concentrations might mitigate the climate change effects on yields, if climate change is not severe. Under all scenarios examined in the EPA report, relative yields were higher in northern areas (that is, yield decreases might be greater in southern areas). The results of all four scenarios used for this report show a northward shift in productivity. Crop acreage in Appalachia, the Southeast, and the southern Great Plains could decrease, while crop acreage in the northern Great Lakes states, northern Great Plains, and the Pacific Northwest could increase, although glaciated soils in northern areas would limit the increase. Irrigation practices could also be affected. The need for irrigation could increase because irrigated crop yields would be more stable than dryland yields

under conditions of increased heat stress. How much more irrigation is actually used would depend in part on the cost of irrigation and the price of crops.

There are many sources of uncertainty in these results. One source is the limited abilities of the global climate models. As mentioned earlier, the GCMs are better at estimating global climate than regional climate. Regional precipitation patterns are uncertain. Changes in extreme events (e.g., storm frequency and heat waves) were not considered. The scenarios examined in this study only examined changes in average climatic conditions, not in variability. The results may have been different had we also considered changes in variability. They would have been different had changes in pests been considered. Only a limited number of secondary effects and feedback effects were considered.

Long Term Activities

In summary, Mr. Chairman, we are only beginning to understand the problem of climate change. It is therefore important to develop a strategy which is malleable and can accommodate new information.

EPA, along with other Federal agencies, intends to be an active participant in the formulation of a Federal research agenda that supports the needs of policy makers and in future debates over strategies to adapt to climate change or to limit emissions. The development of a national policy will be complex and the formulation of a coordinated international response may take many years. Much work remains to be done by the research community to understand emissions, the interactions of emissions with the biosphere, and the ultimate effect on man and the environment of increasing greenhouse gas emissions levels in the atmosphere. EPA looks forward to working with interested federal agencies to exchange research and policy findings with other countries.

Mr. Chairman, thank you for your invitation to present testimony before the Committee. This has been a welcome opportunity to discuss EPA's efforts on this important and complex issue. I would be pleased to answer any questions you may have.

(Exhibits and charts follow:)

EXHIBIT 1

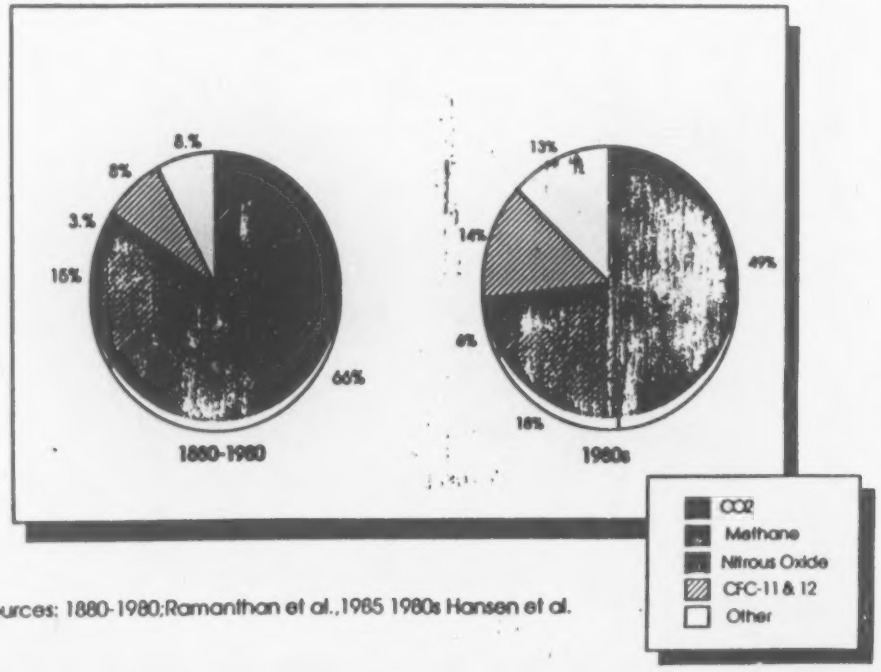
EXAMPLES OF IMPORTANT TRACE GAS SOURCES

Trace Gas	Sources
Carbon Dioxide (CO2)	Combustion/Deforestation
Chlorofluorocarbons (CFCs)	Refrigerants/Packaging/Solvents/Other
Methane (CH4)	Rice/Wetlands/Livestock/Tundra/Landfills
Nitrous Oxide (N2O)	Combustion/Soils/Fertilizers
Nitrogen Oxides (NOX)	Airplanes/Stationary Combustion/ Transportation
Carbon Monoxide (CO)	Transportation/Biogenic/Other Combustion

US Environmental Protection Agency

EXHIBIT 2

Greenhouse Gas Contributions to Global Warming



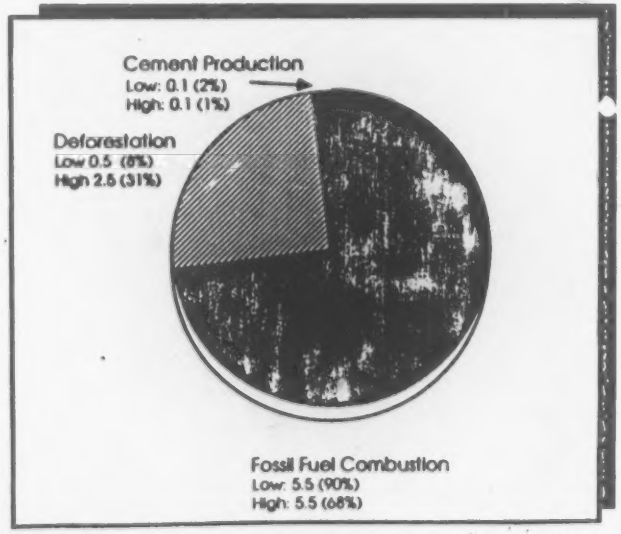
Sources: 1880-1980;Ramanthan et al.,1985 1980s Hansen et al.

EXHIBIT 3

US Environmental Protection Agency

Estimated Sources of CO_2 Emissions

(10^{15}g of CO_2)



Fossil Fuel Combustion:
United States
USSR
China

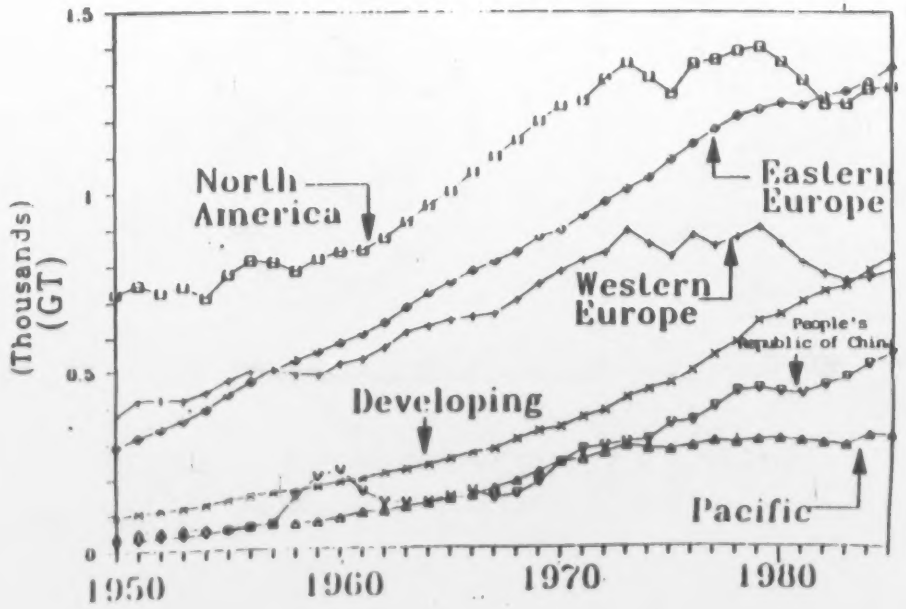
Deforestation:
Brazil
Indonesia
Colombia

Cement Production:
China
USSR
Japan

Sources: Rotty, 1987; Houghton, et al, 1987; Cicerone, 1988.

EXHIBIT 4

ANNUAL FOSSIL FUEL CO2 EMISSIONS BY WORLD REGIONS 1950 - 1985



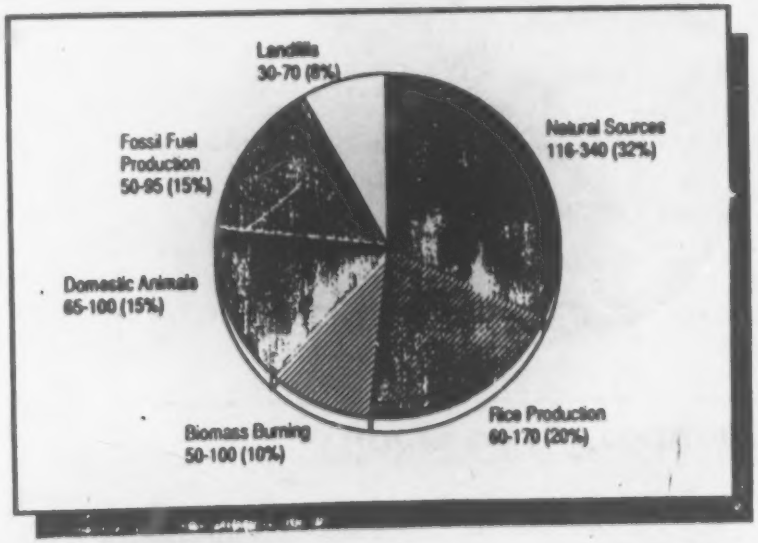
Rotty, Personal communication, 1987

EXHIBIT 5

US Environmental Protection Agency

Estimated Methane Emissions by Source

Range (10^{12} g of CH_4) & Central Value



Top Three Producers:

Rice
- India
- China
- Bangladesh

Domestic Animals
- India
- USSR
- Brazil

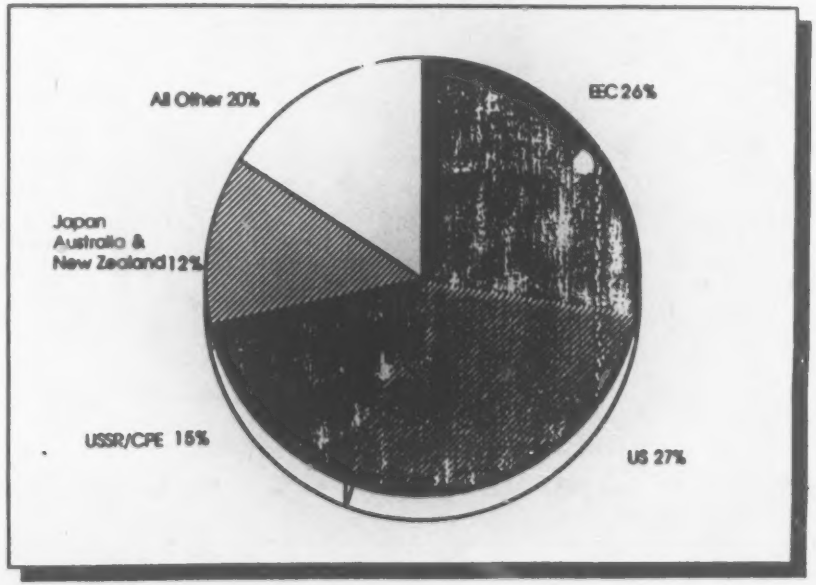
Fossil Fuels
- United States
- USSR
- China

Sources: Bolle et al. 1986; Matthews & Fung, 1987
Crutzen et al. 1986; Hazapfel-Pschorn and Seiler, 1986;
Seiler & Conrad, 1987; Lerner et al. 1988.

US Environmental Protection Agency

EXHIBIT 6

Global CFC Production



Sources: Chemical Manufacturers Association, 1986;
US EPA, 1988.

Exhibit 7

The Potential Effects of Climate Change on the United States

Report Format

National Impact Studies

- Agriculture
- Water Resources
- Forests
- Sea Level Rise
- Biodiversity
- Human Health

Regional Impact Studies

- California
- Great Lakes
- Southeast
- Great Plains

Research Needs

Policy Considerations

EXHIBIT 8

U. S. Environmental Protection Agency

Limitations of the Study

Many Effects Are Not Included (e.g., Fresh Water Wetlands, Effects On Other Regions)

Limited Number Of Secondary Effects And Feedback Effects Considered

Results Are Based On General Circulation Models, Which Have Limited Capabilities

- Regional Precipitation Patterns Uncertain
- Changes In Variability Are Not Considered
- Changes In Extreme Events (e.g., Storms) Are Not Considered

Effects Models Also Have Limitations

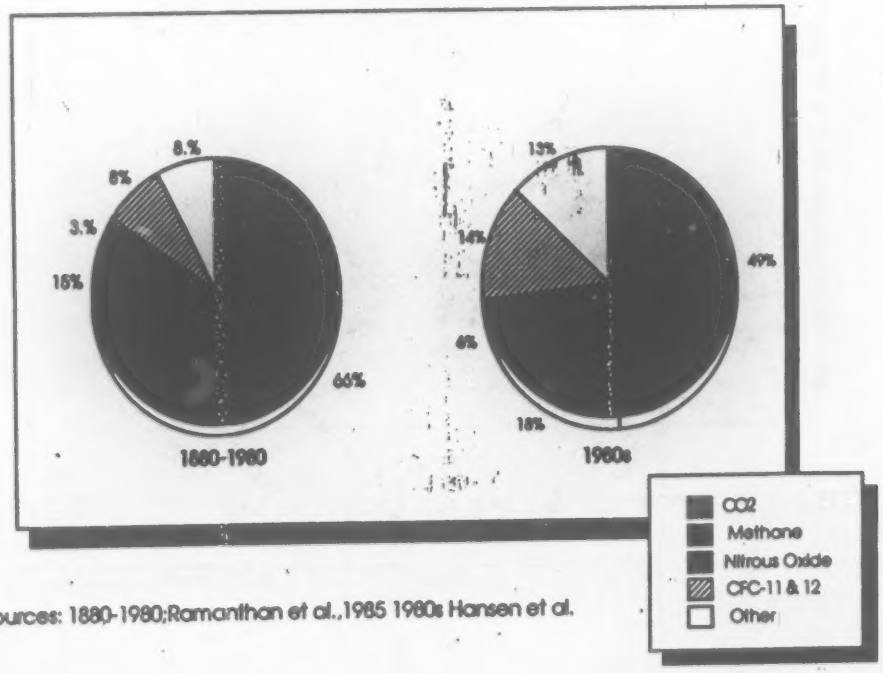
- Calibrated On Historical Data
- Field Experiments Cannot Be Done
- CO^2 Fertilization Only Partially Included

Impact Of New Technologies Considered In Only A Few Cases

Copies of all the charts that Linda Fisher used in her presentation follow:

US Environmental Protection Agency

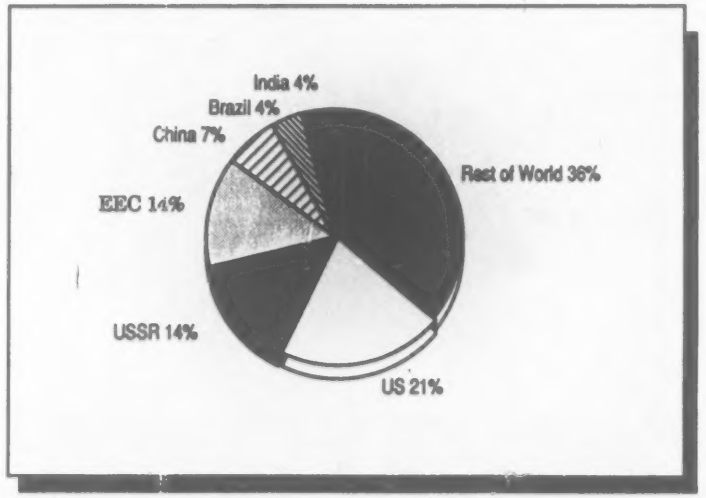
Greenhouse Gas Contributions to Global Warming



Sources: 1880-1980;Ramanthan et al.,1985 1980s Hansen et al.

US Environmental Protection Agency

Regional Contribution to Greenhouse Warming 1980's



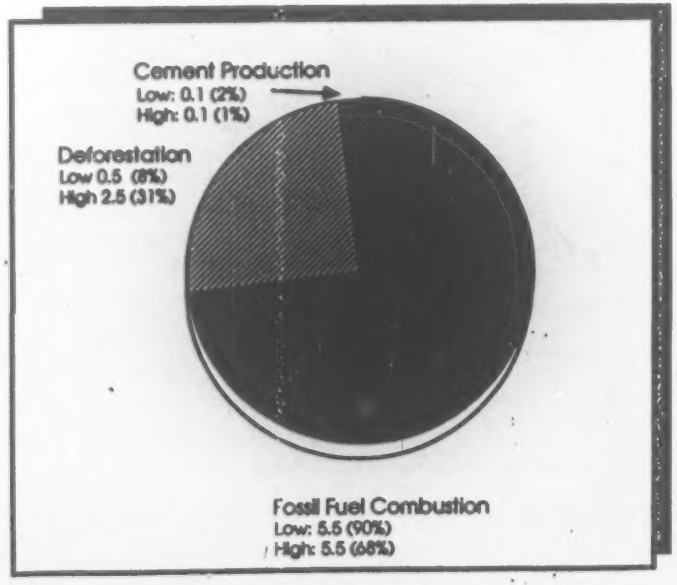
Sources: EPA (1988), Tirpak (1986), United Nations (1987), US Bureau of Mines (1985), IRRI (1986), FAO (1987,1986), Bolle, et al. 1986), Rotty (1987), Lerner, et al. (1987), Seiler (1984), WMO (1985)

CHART 3

US Environmental Protection Agency

Estimated Sources of CO_2 Emissions

(10^{15} g of CO_2)



Fossil Fuel Combustion:
United States
USSR
China

Deforestation:
Brazil
Indonesia
Colombia

Cement Production:
China
USSR
Japan

Sources: Rotty, 1987; Houghton, et al, 1987; Cicerone, 1988.

CHART 4

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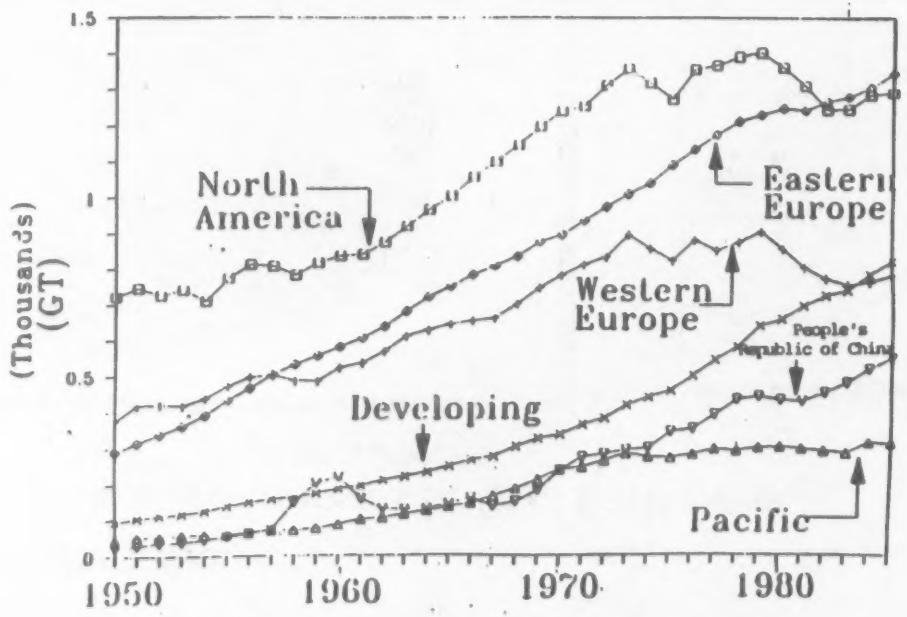
1950 – 1985



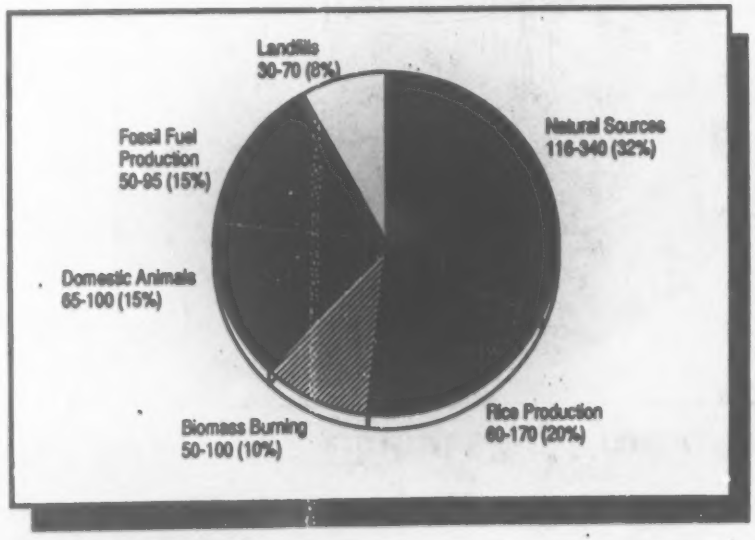
Rotty, Personal communication, 1987

CHART 5

US Environmental Protection Agency

Estimated Methane Emissions by Source

Range (10^{12} g of CH_4) & Central Value



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- China
- Bangladesh

Domestic Animals
- India
- USSR
- Brazil

Fossil Fuels
- United States
- USSR
- China

Sources: Bolle et al. 1986; Matthews & Fung, 1987
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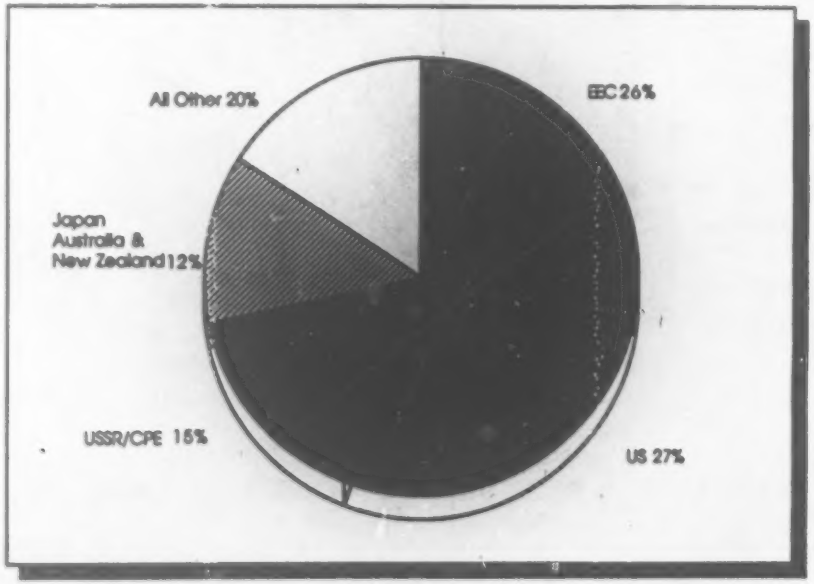
Seiler & Conrad, 1987; Lerner et al. 1988.

US Environmental Protection Agency

Global CFC Production



Sources: Chemical Manufacturers Association, 1986;
US EPA, 1988.

CHART 7

The Potential Effects of Climate Change on the United States

Report Format

National Impact Studies

- Agriculture
- Water Resources
- Forests
- Sea Level Rise
- Biodiversity
- Human Health

Regional Impact Studies

- California
- Great Lakes
- Southeast
- Great Plains

Research Needs

Policy Considerations

CHART 8

Results from National Impact Studies

Agriculture

- Effects on Crop Yields Uncertain
- Crop Acreage and Productivity May Shift Northward
- Demand for Irrigation May Rise

Water Resources

- Changes in Snowmelt and Evaporation
- Increased Demand for Water
- Water Quality in Many Basins Could Change

CHART 9

Results from National Impact Studies

Forests

- Changes in Forest Species Composition
- Reduction in Forest Ranges
- Forest Declines May Occur in 30 to 80 Years

CHART 10

Regional Results

California

- Early Runoff Could Cause Water Management Problems
- Sea Level Rise Will Affect Size, Salinity, and Environment of San Francisco Bay
- Climate Change Will Affect Air Quality

Great Lakes

- Average Lake Levels May Drop 0.5 To 2.5 Meters And Ice Cover May Be Reduced
- Thermal Stratification Of Lakes Could Increase
- Forests Could Change Number And Composition
- Northern Agriculture May Benefit

CHART 11

Regional Results

Southeast

- Potential Reduction in Agriculture
- Many Forests Could Be Converted To Grasslands
- Coastal Fisheries Will Be Threatened By Higher Water Temperatures And Loss Of Wetlands Fromn Sea Level Rise

Great Plains

- Crop Acreage Estimated To Decline
- Demand For Irrigation Would Increase

CHART 12

POLICY OPTIONS THAT EPA IS CURRENTLY ANALYZING

- **ENERGY POLICIES**
  - Improvements in End-Use Efficiency
    - * Transportation
    - * Residential
    - * Commercial
  - Electricity Production
  - Industrial Processes
- **EMERGING TECHNOLOGIES**
  - Renewables
  - Redesigned or More Energy Efficient Technologies
- **AGRICULTURAL PRACTICES**
- **DEFORESTATION AND REFORESTATION**
- **LDC IMPLICATIONS AND INTERNATIONAL PROGRAMS**
- **CFCs: ENCOURAGING RATIFICATION OF MONTREAL PROTOCOL**
- **NOx/SOx/CO/OZONE CONTROL PROGRAMS**

CHART 13

Current Government Activities

- Major Research Programs Being Developed By NASA, NSF, EPA, And Other Agencies
- Intergovernmental Panel On Climate Change Formed By UNEP/WMO To Consider Science And Policy Responses
- Domestic Response Options To Be Assessed By DOE/EPA/Other Agencies In Response To Global Climate Protection Act And Other Mandates
- International Impacts Analysis To Be Fostered In Cooperation With UNEP

Senator BOSCHWITZ. Dr. Bentley, I have to apologize to you. You know how doctors are. This is not the Senate doctor. One of the few, real fine advantages of being a Senator is that usually you can call up the doctor and go whenever you like. But this is not such a situation. So I must excuse myself.

I understand that an effort is being made to see how long the chairman is going to be. I do not know what other Senators are here. I, myself, did not know about this hearing until yesterday. My appointment is a matter of some urgency, so I do need to leave, and I hope that you will excuse me.

I do not know exactly what other Senators are present in Washington. I know the chairman is at a Steering Committee meeting—a Democratic Steering Committee. They are up to some mischief over there, you know. God knows how long that will be. I will call a recess at this time, and I do not think it will extend beyond 15 or 20 minutes. So I thank you for being patient with us, and thank the other witnesses for coming, and again compliment the chairman for scheduling this hearing at this rather unorthodox time in the Senate's schedule, thereby accentuating the importance of this issue. And I share a sense of that importance.

Dr. Bentley, thank you for coming and we will receive your prepared statement for the record.

We will stand in recess until the return of the Chair.

[Whereupon, at 11:17 a.m., the committee recessed and was adjourned by James M. Cubie, chief counsel, at 11:25 a.m.]

EDITOR'S NOTE.—Early in the One Hundred First Congress, a committee print on global warming will be issued by the Committee on Agriculture, Nutrition, and Forestry, prepared by the Congressional Research Service.

[Material submitted for inclusion in the record follows:]

Statement of Orville G. Bentley
Assistant Secretary, Science and Education
U.S. Department of Agriculture
Before the Committee on
Agriculture, Nutrition and Forestry
United States Senate
December 1, 1988

Mr. Chairman, I appreciate the opportunity to appear before you and the members of the committee today to discuss activities of the U.S. Department of Agriculture (USDA) as they relate to the potential effects of global warming on U.S. agriculture. My testimony includes responses to the questions contained in your letter to the Secretary of November 18, 1988.

The Secretary has assigned me, as the Assistant Secretary of Agriculture for Science and Education, to represent the Department on the Federal Coordinating Council for Science, Engineering and Technology (FCCSET), Committee on Earth Sciences (CES). By virtue of this responsibility, I serve as the principal coordinator for USDA's activities relating to research on global climate change. As a member of the Committee on Earth Sciences, I serve as liaison with other government agencies concerned with global climate change issues. I have with me Dr. Norton D. Strommen, Chief Meteorologist, World Agricultural Outlook Board, who works closely with me on all climate-related matters.

Concerns about the effect of climate change on agriculture are not new to USDA. The potential exists for climate change to impose significant adverse effects on agricultural production. Several strategic planning activities have spanned the past 12 to 15 years. The most recent effort was completed and published in three volumes by the National Defense University, Fort McNair, Washington, D.C. These publications reflected the best estimates of our future climate based on state-of-the-art knowledge at that time. But since then new information has become available, including the potential threat of elevated levels of ultraviolet radiation stemming from stratospheric ozone depletion. This threat, added to those stemming from increased atmospheric carbon dioxide concentration, give USDA valid reasons to be concerned about the potential effects of climate change in this Nation, as well as in the world.

USDA is closely monitoring the reports of the carefully documented increases in levels of carbon dioxide, methane, nitrous oxide, chloroflurocarbons and other trace greenhouse gases in the environment. All of these gases can, in theory, contribute to the warming of our atmosphere. In addition, some of them deplete ozone from the stratosphere, reducing the effectiveness of the earth's ultraviolet radiation shield. Carbon dioxide, in addition, can have a direct positive effect on the growth of crops.

The Department's research program for global climate change has two basic parts: 1) dealing with the impact that changing climate could have on the stability and productivity of our natural resource and agricultural ecosystems; and 2) developing strategies to reduce climate change by managing natural resources and agricultural ecosystems to sequester carbon dioxide and reduce the emissions of other greenhouse gases. As the lead food agency, USDA's primary responsibility is with the first of these, but there are significant opportunities for USDA to make a difference in the second -- particularly in the management of our forests and agricultural crop production, as I will point out in more detail later.

Mr. Chairman, we agree with the statement in your invitation to testify that the nature and pace of climate change is uncertain and that there appears to be a lag between emissions of greenhouse gases and their impact on climate. This lag time presents special difficulties in forest management. The age of some forest stands is over 100 years. The Forest Service is faced with assessing the potential impact of future climate changes, as well as assessing the impact of changes in local air pollution. The forests that exist now were produced under different environmental conditions than exist today. Even without future climate changes, tomorrow's forests could be quite different.

Even though the nature and pace of climate change is uncertain, the lag time involved in its potential impact on agricultural systems makes it essential that we do not wait until the change occurs to develop response strategies. A healthy agricultural system is essential to the Nation's security. Anything as critical as our food, fiber, and water supply requires that we have the capability to deal with a range of future possibilities, including the worst case.

Dealing with possible future scenarios that have never existed requires a new approach to our research. No longer can we extrapolate past experience into the future. To deal with this future we must understand the basic physical, chemical and biological processes involved in complex ecosystems with sufficient accuracy to predict responses to any possible climate scenario. Because we cannot conduct experiments on the actual system of the future, we must construct simulation models for study. This is a formidable task. The effects of global climate change cannot be assessed by focusing narrowly on only one or two specific sources of effects or ecosystem receptors.

Because climate change will induce a multiple set of stress factors on the agricultural system, predictive models to deal with it must be comprehensive. A USDA strategic plan for climate change research must recognize that for different applications separate model types will be required. These models must be developed during the early stages of data collection and will serve as the framework for monitoring and defining future research needs.

Our agriculture is highly diverse across the Nation. A model that predicts possible climate change at a global or national scale is of little value in making intelligent decisions related to forest and agricultural productivity. We need climate prediction at the local and regional scale, and particularly we need to know the distribution of rainfall and temperature throughout the year, and the variability of these patterns from year to year. We realize that today's computer-driven models do not now permit predictions of future climate and environment to be made at this scale, but we are working closely with those who are developing global circulation models to help them understand the agricultural needs based on the complex interactions between climate and agriculture and forestry production. These interactions must include the capability of managers to adapt either through changing the genetic structure of crops, plants or through other management options that are available from application of existing agrometeorological knowledge.

Agencies of the USDA included in an effort to develop a strategic plan for climate change research are: the Agricultural Research Service (ARS), Cooperative State Research Service (CSRS), Forest Service (FS), Soil Conservation Service (SCS), and World Agricultural Outlook Board (WAOB). In addition, the Economic Research Service (ERS) and Extension Service (ES) will conduct policy analyses and extend new management practices to farm operators. These agencies form a team with the capability of addressing the major components of natural resource and agricultural ecosystems and their responses to global climate change in the U.S.

The WAOB, the hub of a network of cooperating agencies, is responsible for coordinating the estimates of the world's agricultural production in real time on the basis of environmental data from a number of sources. This agency and its cooperators have developed databases and analytical techniques that represent a substantial resource for predicting world crop production under a range of climate scenarios. Global climate warming could cause significant reduction of food production of some countries. Under some estimates of possible sea level rise, for example, food production from low-lying countries such as Bangladesh could be nearly eliminated. ERS will help assess the impact such production displacements could have on the world market and changes in demands that could be imposed on the U.S. agricultural production system.

The SCS has developed and maintains the Nation's database of soil and, to a lesser extent, surface water resources. This soils database will be singularly important in assessing the potential impact of regional changes in climate on agricultural productivity. One possible scenario predicted by one global circulation model is for the Corn Belt to move northward. If the soils to the North were equally deep and fertile, as those of the Corn Belt, such a change might only represent a geographic displacement of production. But the soils to the North have been glaciated, and generally have much lower water holding capacity and fertility. The productivity of any site depends on both climate

and soil resources. SCS will provide the needed soils data for predicting the impact of climate change on agricultural productivity and for developing strategies for managing soil and water resources to undergird a productive and sustainable agriculture with a changed climate.

Climate change may also have significant impact on the Nation's forests and related ecosystems. These changes would require FS and other land managers to respond with effective management practices to protect and maintain forest health and productivity. There are two basic issues or questions that must be addressed. What effect might climate change have on American forests, and what should forest managers do to be prepared to sustain the future health and productivity of American forests?

A number of future scenarios have been constructed from climate change predictions and some include major changes in the distribution of important timber species. Since public lands in the west are also the major source of water for agriculture, domestic and industrial use, future water supply and quality are also issues that must be addressed. Protection of our renewable resources from fire, insects and diseases is also important. Future protection required to maintain the health and productivity of our forests needs to be determined.

Most strategies to reduce the impact of the greenhouse effect call for energy conservation or conversion to alternate energy sources to reduce the carbon dioxide flux to the atmosphere. An aggressive reforestation or afforestation program could theoretically change the direction of carbon flux. It would take a reforestation program in which 100 million hectares, or approximately 2.5 percent of the earth's forests, of vigorous, rapidly growing, wood vegetation planted annually to offset man's contribution to atmospheric carbon dioxide by fossil fuel combustion.

The recently passed and signed Forest Ecosystem and Atmospheric Pollution Act of 1988 (PL 100-521) identified the need for research on effects of atmospheric pollutants on forest ecosystems. The act recognized that multiple stresses may be responsible for forest decline. The Forest Service Strategic Research Plan calls for a four-element program addressing: Effect of the Atmosphere on Ecosystems, Effects of Ecosystem Changes on the Atmosphere, Assessment of Long-Term Changes, and Ecosystem Modeling, in order to apply research finding to management of our renewable natural resources.

FS research will contribute significantly toward our capability to predict species distribution for future climate scenarios. The long-range renewable resource management program will focus on the development of 1) physiologically-based models to predict the effects of possible global climate changes, 2) models showing the biophysical effects of such changes, 3) methods to link these models, and 4) economic impact and risk assessment models.

CSRS effectively links together the resources of the Nation's agricultural experiment stations and forestry schools. Located in all 50 States, Guam, the Virgin Islands and Micronesia, these institutions provide the expertise of university scientists

in developing the fundamental theories and technology needed to predict and validate global climate change and its consequences to local and regional agriculture and forestry.

University scientists have been organized in a regional research program for several years with a number of projects which specifically work on agricultural climatology, crop, forage and forest responses to environmental influences, including carbon dioxide, ozone and other gases, temperature, light, humidity and all other environmental variables. The universities and experiment stations have programs in genetics and biotechnology in place to develop crops, animals and forest trees adapted to conditions which will be present in the future.

With substantial funding from the Department of Energy (DOE), ARS is developing considerable expertise in the construction of computer facilitated, process level crop simulation models. In cooperation with university scientists, ARS has pioneered the development of computerized agricultural decision support systems using artificial intelligence techniques to help farmers make decisions for managing irrigation, fertilization and other crop management factors.

Recently funds have been appropriated for incorporation of ultraviolet radiation (UV-B) as a specific variable in these crop simulation models. With expanded support, ARS scientists will develop a library of modules for physiologically-based crop growth simulators that will include atmospheric carbon dioxide and UV-B radiation intensity as explicit variables. These modules will serve as a foundation for computerized decision support systems for managers of agricultural systems that include a range of crop and animal enterprises. These farm-level decision support systems will, in turn, provide the foundation for models constructed to assess the risk and economic impact of possible global climate change for the Nation and for the world. ARS scientists will work closely with ERS and others to develop linkages between these models and economic models. Considerable effort will be required to develop the basic knowledge of the processes involved in these models as well as the data required to run them.

The current emphasis and concerns about global climate change are placing added pressure to ongoing research and development programs, as previously indicated. USDA, through its network of Federal and university research facilities distributed throughout the U.S., has the capacity to redirect research activities and initiate new projects related to climate change. Research on southern ecosystems would be transferrable north, should warming trends cause growing zones to migrate northward. Research locations in semi-arid areas can provide data for adaptation to areas that might become drier with climate change. USDA can use much of its ongoing research to support the development of new knowledge and technology for the eventualities of climate change.

ERS has the capacity to develop policy analyses to provide the Secretary of Agriculture with options for encouraging regional shifts in cropping systems, conservation reserves and acreage

set-asides to maintain strategic reserves for food. Much of its success, however, will depend on the lead time that can be gained through accurate predictive capability through simulation modeling.

This type of research requires considerable computer capability and large-scale databases. To acquire such massive data sets in the short period indicated will require major shifts in currently funded research projects in ARS, FS, and at the agricultural experiment stations.

Thank you for the opportunity to present the current state of USDA research activities related to the potential effects of global climate change.

November 30, 1988

The Honorable Patrick Leahy
Chairman
Committee on Agricuture, Nutrition and Forestry
U.S. Senate
Washington, D.C. 20510

Dear Chairman Leahy:

The American Soybean Association appreciates the opportunity to offer comment on the subject of global warming. We would appreciate inclusion of our comments with the committee's hearing record.

The dangerous trend of global warming is predicted to adversely effect all sectors of United States agriculture. If the greenhouse effect is not controlled, a significant increase in mean annual temperature, greater frequency of droughts, major crop losses, and strains on water supply can be expected.

We believe that a discussion of global warming must address its root causes, including the practice of tropical deforestation. Forest clearing is responsible for 15-30% of global warming and is presently occurring at phenomenal rates throughout the tropics. If this destruction continues, a multitude of environmental disasters will ensue, and tropical forests will be completely eradicated during the next century.

Again, we must look to the root causes of the problem for the keys to a solution. If deforestation is arrested, a major source of carbon emissions will be eliminated and the greenhouse effect will be slowed. But neither deforestation nor associated global warming can be stopped if the Third World debt crisis is ignored. Indebted countries cannot develop the financial or political stability necessary to enforce sound environmental policy. The environment is suffering serious, irreversible damage.

The need to acquire foreign exchange for debt payments encourages rash, destructive measures like deforestation. This "export at all costs" philosophy is detrimental to the environment and economies of both debtor and creditor

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nations. Gross misappropriations within the debtor countries lead to hunger, malnutrition, and increased forest destruction. Farmers in developed countries suffer the loss of potential marketplaces for their goods and greater competition in third-country markets from heavily subsidized exports of the Third World.

International cooperation from a wide range of interests is essential to the effective resolution of these interrelated problems. We believe the best initiative includes a conditional write-down of debt that would engage the participation of developed nations, lending institutions, and debtor countries themselves. Debt forgiveness and future lending plans should require recipient countries to pursue sound environmental, political and economic policy. Beneficiary nations must end rain forest destruction, provide for improved nutrition of their citizens, establish and sustain democratic government, and implement free trade practices.

If the debt situation is not effectively managed, global warming, deforestation, and other threats will worsen. Governments, religious groups, environmentalists, humanitarians, financial institutions, and the agricultural sector all stand to benefit from a long-term resolution.

Now is the time for concerted action.

Sincerely,

James Adams

James Adams
President

cc: Honorable Richard Lugar

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